EUROPEAN SCIENCE EDUCATION RESEARCH ASSOCIATION ESERA

Virtual Doctoral Network 2020

(28th June – 4th July)

OXFORD BROOKES UNIVERSITY

DEPARTMENT OF EDUCATION

UNIVERSITY OF OXFORD

Book of Synopses

ESERA Virtual Doctoral Network

ESERA Virtual Doctoral Network

NOTE:

Due to the Covid-19 pandemic and the associated travel restrictions, unfortunately the ESERA Summer School scheduled to take place in Oxford will no longer take place.
In order to support the doctoral students who had signed up to be part of this summer school, ESERA has decided to hold a Virtual Doctoral Network event during the same timeframe as the original summer school from June 28th -July 4th 2020. The event will include feedback from mentors, discussions with peers and social activities through a virtual environment. ESERA hopes that the future summer schools will resume in physical locations as life returns to normal. To provide the participating students with context below is a brief outline of the ESERA School Experience

ESERA Summer Schools Explained

ESERA summer schools have been biannual events for science education PhD students since 1993. Due to increasing popularity, however, these week-long programmes they are now held on an annual basis at various European locations.

The ESERA Summer School is designed to provide a variety of learning opportunities for doctoral students to present, discuss and reflect upon their research projects.

Each participant will have theoretically designed their projects and collected some data (e.g. completed the pilot study or be in the early stages of data collection). Additionally, they will also be beginning to (or be part way through) the process of analysing this data.

The summer schools are organised so that every doctoral student works in a small supportive group of seven peers and two more experienced science education researchers who take on the roles of mentors (see section 7).

Students present their research work in a number of ways,

i. formally to their 6 peers and 2 mentors within their groups;
ii. less formally to other fellow students/mentors during a poster presentation, and
iii. informally at any time during the summer school.

This provides several opportunities to discuss and reflect on their work over a week.

There is also a plenary presentation and a choice of workshops focused on different aspects of carrying out research.

The maximum number of students attending any summer school is 49. There are usually 14 mentors (see section 6), two assigned to each group of seven students. There are also staff who will be from the local organising committee supporting the general running of the summer school (section 1).

If more than 49 doctoral students apply, participants are selected to ensure diversity of countries and research traditions. Applicants should also be aware that to derive maximum benefit from the summer school they should not attend too soon before conceptualising and beginning empirical work nor too late after drafting their thesis. Applications were welcome from any PhD student who is a member of ESERA.

If more than 14 staff members apply to attend the summer school, participants will be selected depending on a number of criteria including the extent to which they have supervised doctoral students (to completion), the nature of presentations and workshops they can offer for students attending the summer school. All staff participating in the summer school must be members of ESERA. Previous experience of PhD supervision is desireable, but staff do not need to currently be supervising a PhD student.

The first ESERA summer school was held in Zeist, the Netherlands, in 1993. A second summer school took place the following year, 1994, in Thessaloniki, Greece. Since then, summer schools were held at two-year intervals until 2017 when by vote of the membership, yearly summer schools were tried. The repeated trial in České Budějovice, Czech Republic at the site of the 2016 and 2017 summer school with the same organizing group and facilities proved to be a real success! Since 2016 the ESERA summer school has continued to be successful on a year-by-year basis.

Previous ESERA summer schools, have been held at:

- 2019 Chania, Greece
- 2018 Jyväskylä, Finland
- 2017 České Budějovice, Czech Republic
- 2016 České Budějovice, Czech Republic
- 2014 Kapadokya, Turkey
- 2012 Bad Honnef, Germany
- 2010 Udine, Italy
- 2008 York, United Kingdom
- 2006 Braga, Portugal
- 2004 Mülheim, Germany
- 2002 Radovljica, Slovenia
- 2000 Gilleleje, Denmark
- 1998 Marly-le-Roi, France
- 1996 Barcelona, Spain
- 1994 Thessaloniki, Greece
- 1993 Zeist, Netherlands

1. Organising Committee Members

The Virtual Doctoral Network (VDN) is organized by a committee of 13 members from the ESERA executive board (Sibel Erduran, Robert Evans Lucy Avraamidou, and Ellen Henriksen) School of Education, Oxford Brookes University (Deb McGregor and Sarah Frodsham and Nicoleta Gaciu) and the Department of Education, University of Oxford (Ann Childs, Judith Hillier, Liam Guilfoyle and Alison Cullinane).


Alison Cullinane


Bob Evans


Ellen Henrikson


Liam Guilfoyle


Ann Childs


Deb McGregor


Judith Hillier


Lucy Avraamidou

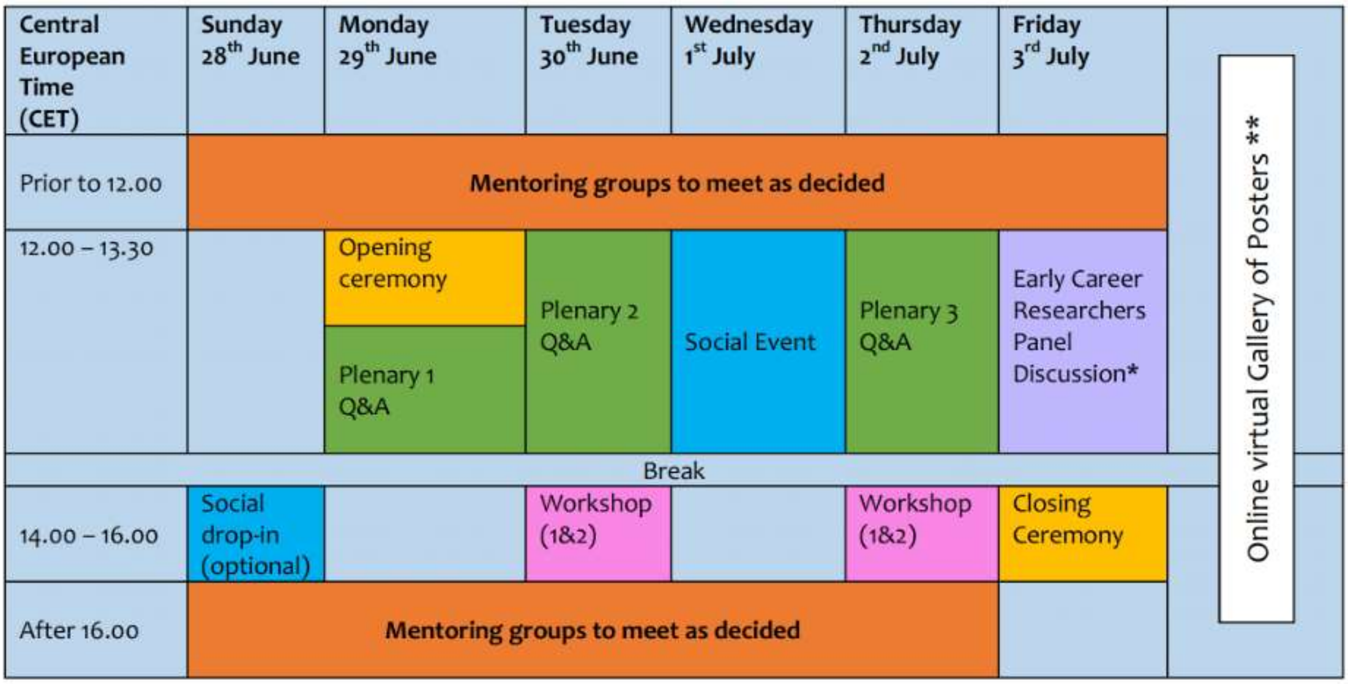

Nicoleta Gaciu


Sibel Erduran


Sarah Frodsham

2. VDN Programme

A programme for the entirety of the VDN can be found below. Please be aware that all timings are at *Central European Time (CET).* See section 7 for time zone differenials.



Central European Time (CET)	Sunday 28th June	Monday 29th June	Tuesday 30th June	Wednesday 1st July	Thursday 2nd July	Friday 3rd July	Online virtual Gallery of Posters **
Prior to 12.00	Mentoring groups to meet as decided						
12.00 – 13.30		Opening ceremony Plenary 1 Q&A	Plenary 2 Q&A	Social Event	Plenary 3 Q&A	Early Career Researchers Panel Discussion*	
Break							
14.00 – 16.00	Social drop-in (optional)		Workshop (1&2)		Workshop (1&2)	Closing Ceremony	
After 16.00	Mentoring groups to meet as decided						

*Participants to email 1 or 2 questions to pose at the Early Career Researcher Panel Discussion by Wednesday July 1st.

** Posters will be presented in a virtual gallery throughout the week.

3. Reviewers

A total number of 36 reviewers participated in the review process. They were:

Jennifer Adams

Sevil Akaygun

Georgios Ampatzidis

Allison Antink-Meyer

Doris Ash

Lucy Avraamidou

Ying-Chih Chen

Ann Childs

Anna Danielsson

Iztok Devetak

Markus Emden

Mariona Espinet

Robert Evans

Xavier Fazio

Judith Hillier

Georgia Hodges

Gerd Johansen

Elizabeth Lewis

Isabel Martins

Deb McGregor

Pasi Nieminen

Lukas Rokos

Martin Rusek

Annette Scheersoi

Renee Schwartz

Mehmet Fatih Tasar

Giulia Tasquier

Sibel Telli

Italo Testa

Radu Bogdan Toma

Veli-Matti Vesterinen

Maria Vetleseter Bøe

Tina Vo

Claudia von Aufschnaiter

Noemi Waight

Sonya Martin

We are extremely grateful to all of the reviewers who gave their time to consider student proposals.

4. Participants

This year there are a total number of 46 PhD students from 13 different nations (see below). They will work in seven groups and each group will be mentored by two academics (see section 6). To view the extended synopses of each student click on their individual names below the photographs or go to section 10.

Aizuddin Mohamed Anuar

University of Oxford, England

Anja Kranjc Horvat

CERN, Switzerland

Argyris Nipyrakis

University of Crete, Greece

Anders Lauvland

University of Oslo, Norway

Anna-Lena Neurohr

University of Vienna, Austria

Arturo Colantonio

University of Camerino, Italy

Athanasia Kokolaki

University of Crete, Greece

Camilo Sebastián Vergara Sandoval

University of Barcelona, Chile

Cristina García-Ruiz

University of Malaga, Spain

Ebru Eren

Trinity College Dublin, Ireland

Eleonora Barelli

University of Bologna, Italy

Elisa Vilhunen

University of Helsinki, Finland

Emily MacLeod

University College London, United Kingdom

Enas Easa

Weizmann Institution od Science, Israel

Feyza Cilingir

Linkoping University, Sweden

Florian Böschl

University of Leipzig, Germany

Harini Krishnan

Florida State University, United States

Isabell K. Rösberg

Leibniz Institute for Science and Mathematics Education, Germany

Filippo Pallotta

University of Insubria, Italy

Gabriel DellaVecchia

University of Michigan, United States

Henry James Evans

University of Copenhagen, Denmark

Jan-Martin Österlein

University of Duisburg-Essen, Germany

Julie Guttormsen

University of South-Easten Norway, Norway

Ketan Dandare

University College London, United Kingdom

Lucia Casas Quiroga

Universidade de Santiago de Cimpostela, Spain

Mária Babinčáková

Pavol Jozef Safarik University, Slovakia

Karolina Matejak Cvenić

University of Zagreb, Croatia

Leonie Lieber

Justus-Leibig University, Germany

Lucy Wood

King’s College London, United Kingdom

Martina Tóthová

Charles University, Czechia

Michiel van Harskamp

Utrecht University, Netherlands

Moritz Waitzmann

Leibniz University, Germany

Rayendra Wahyu Bachtiar

Utrecht University, Netherlands

Sasha Neff

University of Koblenz-Landau, Germany

Miikka Turkkila

University of Helsinki, Finland

Nuril Munfaridah

University of Groningen, Netherlands

Sarah Brauns

Leuphana University, Germany

Sebastian Keller

University of Duisburg-Essen, Germany

Sule Aksoy

Syracuse University, United States

Theila Smith

University of Groningen, Netherlands

Wonyong Park

University of Oxford, United Kingdom

Tanja Mutschler

University of Potsdam, Germany

Uchechi Agnes Ahanonye

University of the Witwatersrand, South Africa

Yakhoub Ndiaye

Research Team 4671 ADEF, France

5. The VDN team

Twenty-seven people from different countries have served as VDN team members. Fourteen of them will be group mentors (section 6 below) and they will work in small groups with PhD students (see section 7). We also have two workshop leaders (section 8) and four plenary speakers (section 9).

6. The Mentors

Meet the 14 mentors below:


Bob Evans


Doris Ash


Isabel Martins


Costas Constantinou


Eliza Rybska


Iztok Devetak


Judith Hillier


Lucy Avraamidou


Lukas Rokos


Martin Rusek


Nicoleta Gaciu


Radu Bogdan Toma


Renee Schwartz


Sonya Martin

7. Group Mentors and Students

Group name	Mentor pair	Countries	Time zones	Students
SASE (Serious About Science Education)	Renee Schwartz Iztok Devetak	Georgia, USA Slovenia	GMT -4 GMT +2	Eleonora Barelli (Italy) Enas Easa (Israel) Ketan Dandare (UK) Sasha Neff (Germany) Julie Guttomsen (Norway) Anja Horvat (Switzerland) Martina Tothova (Czechia)
Isaac Newton	Bob Evans Isabel Martins	Denmark Brazil	GMT +2 GMT -3	Anna-Lena Neurohr (Austria) Athanasia Kokolaki (Greece) Feyza Cilingir (Sweden) Lucy Wood (UK) Michiel van Harskamp (Netherlands) Yakhoub Ndiaye (France) Leonie Lieber (Germany)
The Fellowship	Lucy Avraamidou Doris Ash	Netherlands California, USA	GMT +2 GMT -5	Anders Lauvland (Norway) Ebru Eren (Ireland) Emily MacLeod (UK) Lucia Quiroga (Spain) Maria Babincakova (Slovakia) Moritz Waltzman (Germany)
ESERA Inklings	Judith Hillier Nicoleta Gaciu	UK	GMT +2 GMT +1	Argyris Nipyrakis (Greece) Christina Garcia Ruitz (Spain) Elisa Vilhunen (Finland) Filippo Pallatta (Italy) Sule Aksoy (USA)
The Home Office	Martin Rusek Sonya Martin	Czech Republic Korea	GMT +2 GMT +9	Aizuddin Anuar (UK) Harini Krishnan (USA) Jan-Martin Osterlein (Germany) Karolina Cvenic (Croatia) Sarah Brauns (Germany) Theila Smith (Netherlands)
Marc LeSuf	Eliza Rybska Lukas Rokos	Poland Czech Republic	GMT +2 GMT +2	Arturo Colantonio (Italy) Camilo Sandoval (Chile) Florian Boschl (Germany) Miikka Turkkila (Finland) Rayendra Bachtiar (Netherlands) Sebastian Keller (Germany) Uchechi Ahanonye (South Africa)
The THING CReW	Costas Constantinou Radu Bogdan Toma	Cyprus Spain	GMT +3 GMT +2	Nuril Munfaridah (Netherlands) Henry James Evans (Denmark) Tanja Mutschler (Germany) Gabriel DellaVecchia (USA) Isabell Rosberg (Germany) Wonyong Park (UK)

8. Workshop overview

Two workshops, which will run parallel with each other, have been specifically designed for the 46 PhD students attending this VDN. They will run twice over the course of the week. They are:

Prof. Sibel Erduran - Writing and science education research

First iteration: Tuesday 14:00-16:00 CET

Second iteration: Thursday 14:00-16:00 CET

Time zone differenials can be found in section 7.

The main aim of the workshop is to share with participants some criteria and tools for writing about research in science education. The written text can be parts of a thesis, a journal article or a conference proposal. Although these texts can have different content, there are certain qualities that are common to all. For example, all text needs to be clear so that it is comprehensible to the readers. The workshop will involve participants in tasks to enhance writing skills in science education research. The participants are expected to bring with them up to 2 pages of text that they want to improve, and they want to get feedback on. These texts will be used as part of the workshop to review and to edit the content.

Prof. Alexander Kauertz and Dr Robert Evans - Using Toulmin's argumentation model to plan a research project

First iteration: Tuesday 14:00-16:00 CET

Second iteration: Thursday 14:00-16:00 CET

Time zone differenials can be found in section 7.

When publishing or presenting our research we need to establish a good link between our local project and the bigger picture. The idea of the workshop is to experience how it feels to make sense of data from these two different points of view: one up close and the other as an overview. For the close look participants will be given analysed data from a science museum study and asked to discover if all of the data's potential has been realised. As students work through strategies for getting the most out of this example, they reflect on applications to their own work.

Then the workshop will take a meta-view of this museum study and map it using a theoretical model. With this example in hand, participants will map their own PhD research. This mapping activity should help establish a link in PhD research projects between theoretical backgrounds, literature review, empirical data, research questions and methods of analysis. This overview can then help participants decide on appropriate methods for data analysis, how to use data to underpin assumptions and interpretations, and to decide what results are important to present.

There will be an option to sign up for either or both workshops.

9. Plenary lectures

There are three plenary lectures planned. They are:

Michael Reiss - What kind of researcher do you want to be? Monday, 29 June 2020 @ 12:40 – 13:30 CET.
Time zone differenials can be found in section 7.

Abstract: Books on research methods in education and other social sciences give lots of valuable advice about developing a methodology for one's study and identifying suitable research methods that can be used to help answer your research questions. But there is, perhaps, a deeper question – and one that is less often considered. Namely, what sort of researcher do you want to be? To some extent this is simply about the nature of your methodology and methods – for instance, do you want to do a study that carefully observes what is going on in a setting or do you want to devise and implement an intervention and then examine the consequences of the intervention. But think about what sort of researcher you want to be (not necessarily yet are!). This might mean that you realise your fundamental interest is in facilitating learning, broadening access to science education, tackling inequalities or something else. This keynote will examine these issues. I hope that it will help you to clarify why you are undertaking research and how the work that you do can reflect your values and identity.

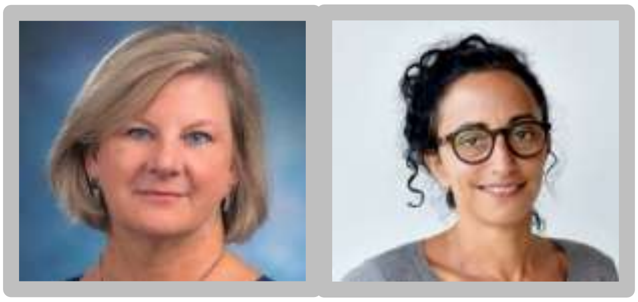
Speaker:
Michael J. Reiss is Professor of Science Education at UCL Institute of Education, University College London, a Fellow of the Academy of Social Sciences and Visiting Professor at the Universities of York and the Royal Veterinary College. The former Director of Education at the Royal Society, he is a member of the Nuffield Council on Bioethics and has written extensively about curricula, pedagogy and assessment in science education and has directed a very large number of research, evaluation and consultancy projects over the past twenty five years funded by UK Research Councils, Government Departments, charities and international agencies.

C. P. Constantinou - Designing for relevance in science education research: examples from formative assessment.
Tuesday, 30 June 2020 @ 12:00 – 13:30 CET.
Time zone differenials can be found in section 7.

Abstract: Formative assessment has received attention for many years as a mechanism for offering timely feedback to students, for enhancing their engagement and for refining the scaffolding of their efforts to attain meaningful learning. Within inquiry-oriented science education, formative assessment presents renewed challenges in terms of what to assess, in what sequence, how to obtain reliable evidence and how to present it to students in a respectful, supportive and effective manner. In this presentation, I will seek to explore one aspect of relevance in science education research: investigating strategies and evaluating tools for teaching and learning. I will highlight specific approaches to formative assessment, including stimulated self-reflection, peer evaluation and structured classroom dialogue. I will provide illustrative examples of research on teachers' use of classroom evidence to guide and support learning. Finally, I will discuss implications for science education research, for teacher preparation and for classroom teaching practice.

Speaker:
C. P. Constantinou is a Professor in Science Education and Director of the Learning in Science Group at the University of Cyprus. He has published extensively on curriculum

design, research-validation of teaching-learning innovations, assessment for learning and the development of transversal competencies such as modeling, investigation, argumentation and creativity. He has a PhD in Physics from the University of Cambridge and has worked at Washington State University and the University of Washington. He is a member of the editorial boards of the Educational Research Review and the journal Learning, Culture and Social Interaction. He is serving as a reviewer in several international research journals including Learning and Instruction, Instructional Science, the International Journal of Science Education and the Journal of Research in Science Teaching. He has been active in international educational research over a period of more than 25 years with research interests that focus on the learning and teaching of science as a process of inquiry and the use of educational technologies as a tool for promoting critical evidence-based thinking. The Learning in Science Group uses the results of this research in the development of online learning environments and research-based teaching-learning sequences to promote conceptual understanding, evidence-informed reasoning and scientific thinking. Dr. Constantinou has co-ordinated a number of projects funded by the European Commission and the Cyprus Research Promotion Foundation. He has participated in the High Level Expert Groups that authored the reports Science Education for Responsible Citizenship in 2015 and Europe needs more Scientists! in 2004. He has served as President of the European Science Education Research Association (www.esera.org) and as Chairperson of the Executive Committee of the European Association for Research on Learning and Instruction (www.earli.org).
Some of his work is accessible
at https://www.researchgate.net/profile/Costas_Constantinou2 and
at https://ucy.academia.edu/CostasConstantinou
He can be contacted at c.p.constantinou@ucy.ac.cy



Schwartz and Avraamidou –
New directions in understanding relationships among science learning experiences, science identity and understandings of the nature of science. Thursday, 2 July 2020 @ 12:00 – 13:30 CET.

Time zone differenials can be found in section 7.

Abstract: Situated within global socioscientific challenges (e.g., public health, climate change, inequality, poverty) we aim at engaging the audience with questions associated with the role of science education research in promoting goals related to equity and social justice. In doing so, we will first provide a brief overview of the existing knowledge base around science learning experiences, science identity, and understandings of the nature of science. Following on that, and drawing on our experiences as researchers, we will highlight opportunities and challenges of being cognizant of one's positionality. We will reflect on the ways in which place(s) and the unique sociopolitical realities attached to specific research contexts might position researchers as insiders/outsiders in studying issues related to science learning experiences, science identity, and understandings of the nature of science. We will engage with questions such as: What is our responsibility as researchers, and to whom should our responsibility be? How do our lives intersect (or not) with the lives of the participants and how do those intersections impact the research process and outcomes? In engaging with these questions we will offer concrete examples from our own research studies in the areas of science identity and the nature of science and we will reflect on the affordances and limitations of specific research approaches, theoretical frameworks and methodologies. We will conclude by gazing forward and exploring new directions in understanding relationships among science learning experiences, science identity, and understandings of the nature of science for the purpose of addressing goals related to equity and social justice in science education research.

Speakers:

Renee Schwartz is a professor of science education in the Department of Middle and Secondary Education, Georgia State University. Her research focuses on the study of epistemological views of science, specifically views of the nature of science (NOS) and the nature of scientific inquiry (NOSI). Through primarily qualitative methods, she examines preservice and practicing science teachers' developing conceptions of NOS and NOSI in various contexts — including authentic science research experiences and classroom-based science learning — to identify effective means of fostering conceptual and pedagogical knowledge.

Lucy Avraamidou is an associate professor of science education at the Institute of Science Education and Communication, University of Groningen, NL. Her research is associated with theoretical and empirical explorations of what it means to widen and diversify STEM participation in school and out-of-school settings through the lens of intersectionality. At the heart of the account of her work is an exploration of minoritized individuals' identity trajectories with the use of narrative and life-history methods.

10. Extended Synopses

Young people's STEM education and aspirations for development: A comparative case study of Malaysia's rural heartland

Azuddin Mohamed Anuar

Abstract

The 'science for development' model proposed by Drori is reflected in many national education policies in the Global South, referring to the West as benchmark for development. Subsequently, Science, Technology, Engineering and Mathematics (STEM) education is prioritised in pursuing economic development. Adopting a postcolonial critique, I foreground rural young people's development-related aspirations at the intersection of their STEM education and place-based culture. This research entails a two-stage comparative case study in Malaysia, including interviews, document analysis and participant observation in the capital city and one secondary school in a rural community. A participatory component is also included in the secondary school. Thematic analysis of the data is guided by a conceptual framework integrating Levinson and Sutton's 'policy as practice' approach and Appadurai's concept of 'capacity to aspire'. In hybrid with STEM education, rural young people's aspirations may offer new possibilities of the 'good life' beyond the dominant economic paradigm.

Focus of the study

As it is conceived of today, 'development' is largely framed in terms of economic growth, capital accumulation, the pursuit of modernity and urbanisation, as well as the expertise of Western science and technology (Corbett, 2016; Escobar, 2012; Esteva, 1999). The hegemonic logic of science-based development flows from the West to be internalised by countries in the Global South, thus influencing political imaginations and subsequent education policies (Alvares, 1999; Caillods, Gottelmann-Duret, & Lewin, 1996).

As a developing nation in the Global South, Malaysia is not spared this influence. To develop the human capital for achieving economic development targets, the Malaysian Ministry of Education (MOE) instituted a target of 60 per cent science & technology (S&T) stream enrolment against 40 per cent arts stream in secondary school (60:40 policy) within the National Education Policy since 1970 (Zainudin, Halim, & Iksan, 2015). In the broader political and societal sphere, the national development discourse is often coupled with the term *dalam acuan kita sendiri* (Malay for 'in our own mould').

I situate this study at the point where the global and national development discourses translate into Science, Technology, Engineering and Mathematics (STEM) education of rural young people in Malaysia. For the purpose of this study, STEM education at once refers to the discursive and curricular adoption of this term in the Malaysian context. Meanwhile, development essentially refers to the pursuit of the 'good life' described by Sen (1999) as the kind that people have reason and freedoms to value. This study foregrounds rural young people who are marginalised in the context of national development in Malaysia, which the World Bank (2015) refers to as "among the more urbanized countries in East Asia, and its urban population continues to increase rapidly" (p. 99).

The aim of this study is to explore the idea of development *dalam acuan kita sendiri* (in our own mould) in Malaysia through rural young people's aspirations from below, as they encounter STEM education—the intermediary of national development from above—in tandem with their place-based culture.

Review of relevant literature

In a comparative study spanning more than 20 countries, Marginson, Tytler, Freeman, & Roberts (2013) describe a broad trend of countries focusing on STEM education as part of their economic policy, framed in relation to human capital theory. This logic can be understood in the Global South through the concept of 'science for development'—science education is deemed instrumental for the production of labour force required for economic, and thus national development (Drori, 1998). More recently, science and STEM education have also been researched in relation to the concept of sustainable development (Eilks, 2015, Onwu & Kyle Jr., 2011; Tikly et al., 2018). Nonetheless, the utility and relevance of STEM education for imagining grassroots conceptions of development is understudied.

Through a postcolonial critique of development, I thus foreground the representation, ways of knowing, and voices of young people at the grassroots, in combination with participatory, communitarian approaches (McEwan, 2019). Through the lens of aspirations, Appadurai's (2004) useful concept of 'capacity to aspire' is selected; this is a capacity that can be practiced and strengthened, while recognising its potential hampering by social circumstances. Appadurai (2004) further argues that aspirations are formed through socialisation, and should be considered a cultural capacity, wherein "culture is a dialogue between aspirations and sedimented traditions" (p. 84). On the matter of culture and rural students, research has suggested the need to ensure synergy between science education and their cultures, traditions and daily lives (Avery, 2013; Kassam, Avery, & Ruelle, 2017).

Literature on rural young people's aspirations have often focused on the pursuit of higher education and careers, as well as the sense of place and process of out-migration in relation to these pursuits (Bjarnason & Thorlindsson, 2006; Chankseliani, 2013; Lowe, 2015). However, scholars have argued that the prevailing emphasis on aspirations in the economic sense overshadows other imaginaries related to spirituality, familial and social relationships as well as community engagement, all of which are tied to leading a meaningful life (Boateng & Löwe, 2018; Tieken & San Antonio, 2016). Collectively, these insights reflect the multiple dimensions of development that can be gleaned through the lens of aspiration. In summary, the conceptual framework in Figure 1 is synthesised based on the review of literature and represents the connection between all the major concepts in this study.

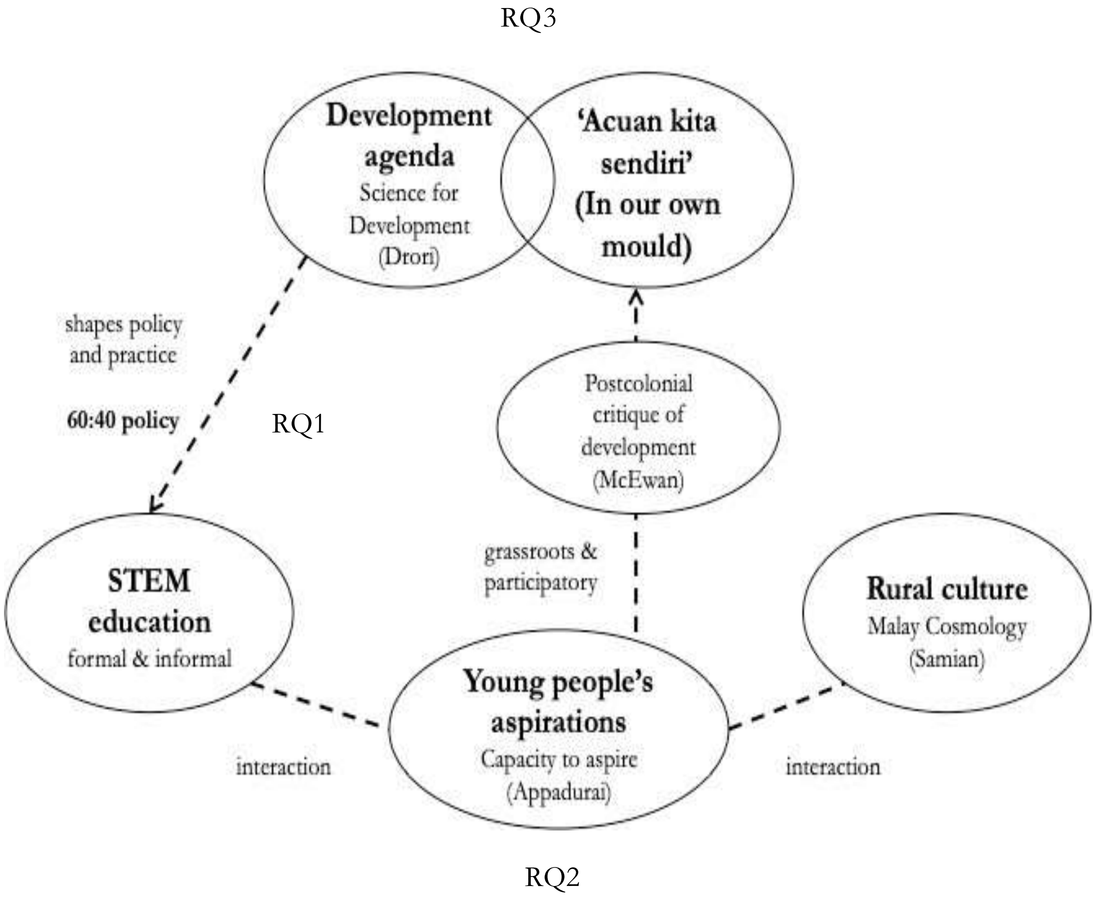


Figure 1: Conceptual framework synthesised from literature review

Research questions

RQ1: How does the 'science for development' model manifest in Malaysia, thus shaping STEM education policy and implementation?

RQ2: How do Malaysian rural secondary school students describe their aspirations for development in relation to their STEM education and their rural culture?

i. How do Malaysian rural secondary school students, their family members and teachers view STEM education influencing the formation of their aspirations?

ii. How do Malaysian rural secondary school students, their family members and teachers view rural culture influencing the formation of their aspirations?

RQ3: How are Malaysian rural secondary school students' development-related aspirations similar and different to, and in hybrid with Malaysia's 'science for development' agenda?

Research design, methodology and methods

I adopt a comparative case study (CCS) approach developed by Bartlett & Vavrus (2017), which entails the tracing and shadowing of phenomenon of interest across multiple scales and sites, along vertical, horizontal and transversal axes. The CCS approach integrates the 'policy as practice' approach developed by Levinson & Sutton (2001), which emphasises the ways and locations where policies are shaped and appropriated as practice by multiple actors. The phenomenon of interest in this study is young people's aspirations for development in relation to STEM education and their rural, place-based culture. I first address **RQ1** (vertical axis) by tracing how this global agenda of 'science for development' manifests at the nation-state level in Malaysia, subsequently translated into STEM education policy and practice. By selecting one secondary school situated in a rural community in the east coast of Peninsular Malaysia, the focus of the second stage will be to address **RQ2** (horizontal axis). This stage entails 5-months ethnographic engagement with young people and related social actors in their lived environment.

In order to address **RQ3** (horizontal axis), the outcomes of **RQ1** and **2** will be subjected to homologous comparison through qualitative analysis. Focusing on descriptions of aspirations as the unit of analysis, the aim is to produce 'thick descriptions' of how young people's aspirations for development—a display of development *dalam acuan kita sendiri* (in our own mould)—are comparable to the national 'science for development' agenda. Throughout the study, analysis along the transversal axis considers how young people's aspirations have changed over time. Elements of the research design are also highlighted in Figure 1.

A combination of methods is employed to source rich data and enable triangulation across all research questions. Underpinned by an ethnographic approach, this study includes semistructured interviews with key actors in STEM education and development, students, parents and teachers, as well document analysis of media publications, curriculum documents, policy reports and other relevant artefacts. I also include observation of STEM-related activities as well as a participatory approach involving co-research and photography with students. Specifically, the participatory approach with students will help address **RQ2**. Participating students will take photographs related to places they deem significant to our discussion of aspirations for development. These photographs will then be used as prompts in the interviews with them. As co-researchers, the students will develop the semi-structured interview protocol for subsequent interviews with their family members and teachers. In preparing them to undertake the role of co-researchers, the students will be trained using the MyShout! protocol developed by Kerawalla (2018).

Data collection

Data collection for this study began in October 2019 and at the time of writing, **RQ1** is the focus of enquiry. So far, five semi-structured interviews have been conducted with key actors in STEM education and national development in Malaysia, with at least three more interviews planned. The interview participants were identified based on deep engagement with the local context in order to identify influential experts relevant to this study. Associated documents such as media articles (71), resource guides on STEM education (3), policy and technical reports (6), brochures/promotional material (6) and MOE circular (1) have also been collected—the respective quantities are included in brackets. These documents were sourced through Internet search, assistance by the interview participants, and attendance at two STEM festivals in the capital city. From January to May 2020, data collection will focus in the rural community and secondary school in order to address **RQ2**. By the time of ESERA 2020 Summer School, the overall data collection phase for this study will be have been completed.

Data analysis and preliminary findings

The data in this study is subjected to thematic analysis following a combination of inductive and deductive data coding (Braun & Clarke, 2006; Kuckartz, 2014) guided by the conceptual framework in Figure 1. For **RQ1**, the interview transcripts as well as the associated documents were subjected to close reading in order to identify emerging themes. I paid particular attention to descriptions related to the ‘science for development’ model as well as its relationship to STEM education in Malaysia. To start, preliminary ideas were noted during transcription phase based on identified patterns in responses. Following this, an iterative process of close reading and comparison across transcripts and documents, as well as theme generation, consolidation and dissection took place. Preliminary findings from thematic analysis indicated that the ‘science for development’ model in Malaysia manifests in three ways. First, other developed countries such as Japan, Singapore, Australia, United States and South Korea are touted as examples for emulation through their respective scientific efforts. Secondly, scientific advancement is framed as spurring high-income national development in relation to the knowledge economy, industrialisation, entrepreneurship and livelihoods. Finally, scientific talent required to realise the promise of development necessitates an emphasis on STEM education, although the content and approach warrant further contextualisation.

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Higher education physics students’ motivations in interactive engagement environments

Anders Lauvland

Introduction

There is an ongoing change in how physics, and science, technology, engineering and mathematics (STEM) in general, is taught in university education. Instruction in physics is becoming more and more based upon the notion of “active learning” or interactive engagement (IE) methods. In IE learning environments students are encouraged to be more active in hands-on and minds-on tasks throughout their learning experience and often receiving feedback from their peers or instructors. This kind of teaching has been reported more effective than the traditional lecture-based instruction, both in drop-failwithdraw rates and learning outcomes[1]. However, it is a familiar notion to many that students do not always have a positive attitude for these kinds of teaching methods[2]. It has also been reported that the student’s feeling of learning is higher for students in a traditionally taught class than in an class reformed using IE – even if their measured learning shows the opposite result[3]. This leads to the question of how motivated students are for learning physics in an active learning environment. This is touched upon, but not covered to a great extent in the literature. Thus, my main research goal for my PhD thesis is:

- *To understand how IE methods of modern university instruction in physics influence students’ motivation and learning.*

Results of such a study can be used in improving higher education in physics.

Background

This study applies an expectancy value theory (EVT) theoretical framework for motivation developed by Eccles and colleagues[4]. The EVT-framework has been widely used to understand student’s choices in STEM-studies in prior research[5]. Two constructs in the framework, *Expectations for success* and *Subjective task values (SVT),* is theorized to be developed with input from several sources, including learning situations, and the two predict the outcome of an achievement related choice. An achievement related choice is, for instance, to attend a lesson or continuing to study physics. The first construct, expectation of success, concerns how well an individual think he/she will do on a specific task. The term has much in common with Bandura’s self-efficacy[7].

The second construct, SVT, comprises four sub-constructs: *Interest enjoyment value*, *Attainment value, Utility value* and *Cost.* Interest enjoyment encapsulates the individual's interest in the task and expectation of enjoyment experienced while working on it. It bears similarities to intrinsic motivation[8]. Attainment value corresponds to how much the individual feels that completing the task is on accord with its perception of its identity. Utility value is the concrete gain from completing the task (e.g. obtaining an academic degree, good job). It shares features with the term extrinsic motivation[8]. Cost is the individual's perceived cost of engaging in a task (e.g.
prioritizing studies over spending time with friends), and is often scaled negatively compared to the other SVTs.

Motivation is highly predictive of choices of, retention in, and performance in physics[5,9]. In the EVT setting, it has been found that students in higher education physics value interest-enjoyment more than the other motivational measures such as cost, attainment or utility[10]. Furthermore, upon starting higher education, STEMstudents report that the studies are more demanding than they expected beforehand[11]. It has been reported for physics students that both interest and self-efficacy tend to drop as students experience their first university physics courses, especially among women, both in lecture based[12] and IE[13] approaches. Gender perspectives are important in physics education research due to the general underrepresentation of women in physics education[14]. Several studies document that men and women on average have different preferences in terms of learning activities, for example, females tend to learn better from collaborative approaches[15], leading physics educators to argue that traditional teacher-centred approaches favour males. On average, men's and women's development of self-efficacy in science education differs slightly[16,17]. Whereas men's self-efficacy arises strongly from actual/perceived achievements on science-related tasks, women rely more on interaction with others. My PhD project addresses such gender differences in physics by studying how male and female physics students develop their motivation for physics in the meeting with different teaching and learning activities. The integration of computational physics, which is becoming a prevalent feature of higher education physics along with IE, makes it possible to study how the collaborative aspect, preferred by women according to the literature, and the computational/technological aspect, more commonly preferred by males, interact with young male and female students' physics motivation.

My study

My PhD project has three components, one (main) quantitative component and two qualitative components, making it a mixed methods project. The research aims/questions can be seen in Table 1.

Table 1: Research aim and questions for the components of the project.

Research aim/questions
1. *Developing an instrument for measuring motivation for physics students.*
2. *How do different subgroups, notably by gender and preferred learning situations, differ in terms of motivation?*
3. *How does students' motivations change over the course of the first two years of study?*
4. *How do different learning activities, such as active learning elements and computations, interact with students' development of motivation?*
5. *How do views on teaching and learning develop among learning assistants (LAs) after a semester of experience as teachers, and do the LAs feel that their way of teaching affects student learning and motivation for the subject?*

The first and main component of this project is quantitative. It is the development and use of a survey intended to observe motivational constructs longitudinally using the EVT framework and other variables considering students' self-reported experience of learning and motivation in different learning situations. Referring to Table 1, this component is intended to satisfy research aim 1, and once data collection is concluded in spring 2021 it will answer research questions 2-4.

The second component (C2) is qualitative. Data will consist of semi-structured focus group interviews with physics students at the University of Oslo from the same cohort as the quantitative survey is addressed to. This will provide a more in-depth description of the development of physics students' motivation using the EVT framework. Referring to Table 1, this study is intended to answer research question 3 and 4.

In **the third component (C3)** I investigate one context where students learn through IE methods, namely group lessons. I assess the view of teaching and learning of the undergraduate or graduate learning assistants (LAs), who facilitate group discussion and problem-solving among the students. These LAs receive a pedagogical training seminar throughout their semester in service[18]. The data consists of focus group interviews and pre-post surveys with Likert-items and open-ended questions. Data is analyzed using inductive thematic analysis[19]. Referring to Table 1, the study is intended to answer research question 5.

In Table 2 the project-time line is displayed. Note that more data will be collected for component 1 and 2 by June 2020.

Table 2: Timeline for my PhD-project.

Year	Semester	**Component 1**	**Component 2**	**Component 3**
1	Fall 2018	Survey development.		Piloting, data collection: -Interview -Pre-post survey
	Spring 2019	Development of survey: -validation interviews and pilot at one university.		Data collection: -Interview. -Pre-post survey.
2	Fall 2019	Adjust survey post pilot. Data collection: -Survey at three universities in Norway.		Presenting preliminary results @ ESERA 2019. Data collection: -Interview -Pre-post survey Outline article #1 on LAs.
	Spring 2020	Data collection: Survey at two universities in Norway.	Data collection. -Focus group interviews	Finish manuscript, article #1.
ESERA summer school				
3	Fall 2020	Outline Article #2, first round of survey results.	Data collection.	

	Spring 2021	Finish article (#2). Data collection at five Norwegian universities, survey component.	Data collection.	
4	Fall 2021	Writing article (#3) survey component – longitudinal survey.	Writing article (#4)	
	Spring 2022	Writing thesis. Finishing article (#3) and (#4).		
	June 2022: Thesis delivery			

Status of the study

The quantitative part, C1, will collect more data for the first round during spring 2020 (two more universities), and this will conclude the first round of data collection. There are some preliminary results outlined below. For C2 data will be collected during spring 2020, and preliminary results are therefore not present. Approximately six hours of focus group interviews with LAs have been conducted for C3, and data collection nears completion.

C1: Preliminary results and discussion

Data has been collected from N = 245 students taking an introductory course in physics at three universities in Norway (UiB, UiT and NTNU), as part of their physics bachelor (26%, 7% female, 18% male), physics teacher education (10%, 5% female, 5% female), physics engineering (64%, 28% female, 36% male) other study programs (10%, 4% female and 6% male). The analysis so far shows that the constructs for student motivations are reliable with a Cronbach's α ranging from 0.77 to 0.87 on items covering constructs in EVT. Table 3 shows construct statistics and effect size estimates, Cohen's d, of differences between male and female construct scores. A score close to five on the mean (M) denotes high e.g. interest for physics, $d > 0$ indicates a higher male score. We see from the last column in Table 3 that gender differences in interest enjoyment and expectation of success are high. This is expected from previous research showing that women tend to have a lower self-efficacy and interest for physics than male students.

Table 3: Construct statistics and effect sizes. Cohen's d estimates are given with a 95% confidence interval in brackets.

	Male			Female			
Construct	M	$Nmale$	SD	M	$Nfemale$	SD	$d$male(95−female % CI)
Interest enjoyment (4 items)	4.14	143	0.61	3.61	96	0.82	0.77 (0.5, 1.03)
Utility Value (5 items)	4.19	143	0.57	4.17	96	0.61	0.04 (-0.22, 0.3)
Attainment value (6 items)	3.99	142	0.62	3.66	96	0.8	0.47 (0.2, 0.73)
Cost (R) (7 items)	2.58	142	0.8	2.33	96	0.89	0.3 (0.04, 0.56)
Expectation of success (4 items)	2.89	142	0.79	2.18	96	0.79	0.9 (0.62, 1.17)
Total (26 items)	*3.51*	*143*	*0.48*	*3.16*	*96*	*0.54*	*0.69 (0.42, 0.96)*

Note:(R) denotes reversed scale for items. Scale in the mean-columns (M) ranges from one to five. Missing data and other gender categories are not included in the data to produce the table values.

C3: Preliminary results and discussion

Focus group data from learning assistants having completed a semester of teaching and a pedagogic training seminar have been analysed, and two themes have been identified so far. The first theme is that LAs have a greater appreciation for conceptual understanding as a goal of instruction. The second theme is that the LAs view of the teacher role has evolved through the LA experience. The LAs state that they now view their role as a facilitator that lets the students be active.

The results' overall indication is that LAs buy in to central aspects of IE.

Next steps

With more data (to be collected Spring 2020) for C1, there will be enough data to validate the EVT-constructs using exploratory factor analysis. It could also be possible to make a structural equation model to describe the interaction between motivation, preferences for different learning activities and/or time spent on different learning activities.

The focus group interviews in C3 will inform how these interactions operate for students and their motivation and physics identity development, as well as provide students' perspectives on the active learning environments facilitated by LAs. Future analysis of C3 data will investigate whether current themes are identified across the entire dataset, and if there are themes that relate LAs perceptions of student motivation and learning in the context of the LAs' own teaching.

Attending the summer school would be hugely beneficial in this stage of my PhD. I am looking forward to seeing how this will provide me with necessary strategies to push my own research forward as well as learning from discussing the work of others. I also expect the summer school to provide an opportunity to branch my network with other young researchers in the field of science education.

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Concept Maps as a Tool for Evaluation of CERN’s Teacher Programmes

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Abstract

With the rising demand for teacher professional development in science and technology, science institutions around the world are increasingly organising professional development programmes. Among them is CERN, the European Laboratory for Particle Physics, which offers teacher programmes for in-service high-school teachers from around the world. To evaluate CERN’s teacher programmes and to ensure that they meet the expectations of the stakeholders a two-part research project was set up. The first part of the research is a Delphi study on goals, objectives, and design features of professional development programmes in general and at CERN or similar large research institutions. Based on the results of the Delphi study, a concept mapping study is being developed.

Here, the research will be focused on documenting changes in teachers’ conceptual understanding of modern physics in general and the development of a coherent knowledge framework within the CERN context.

Keywords: Professional development, Delphi study, Concept maps

Introduction

The results of the recent OECD study showed that over 80 % of teachers worldwide participated in at least one professional development course or programme in 2018 (OECD, 2019). Consequently, many scientific institutions, including various research laboratories such as CERN, are developing professional development programmes (PDPs) for in-service teachers. Among them are CERN’s teacher programmes (TPs) for high-school science teachers from around the world. Here, teachers can participate in national TPs in their national language that last for three to five days, or two-week international programmes in English. Both types of programme offer a series of lectures, guided tours, and workshops on science related to CERN's research. The programmes have been running for over 22 years and welcome up to one thousand teachers per year.

Indeed, the number of participants illustrates CERN’s prominent role in professional development for science teachers. However, it also calls for constant evaluation of the TPs to ensure that the stakeholders’ expectations are met.

Research outline

Following the guidelines for evaluation of PDPs by Guskey (2000), the first step of the evaluation of CERN’s TPs is the clarification of the goals of the programmes and assessment of their value. Here, a Delphi study was designed, where over one hundred CERN TP stakeholders were questioned regarding their expectations of the programmes.

The Delphi study was guided by the following research question:

“Which goals, objectives, and design features of PDPs at large research institutions, such as CERN, can be identified as the most important by a Delphi study with multiple groups of relevant stakeholders?”

With the data collection for the Delphi study finished, the preliminary findings will be presented in the following paragraphs.

The second part of the doctoral research project focuses on the assessment of CERN’s TPs through concept maps. Here, the study will try to answer the research question:

> “To which extent do teachers’ concepts about CERN and particle physics change during their participation at a CERN’s teacher programme?”

This part of the project is in the pilot phase and will be outlined at the end of this synopsis.

Review of the relevant literature

Evaluation of PDPs in science can be a challenging and complicated process, as the programmes are usually embedded in the educational systems (Guskey, 2000; Hewson, 2007). As such, it is vital to approach the evaluation systematically. The initial steps of a well-structured evaluation of PDPs should be the clarification of the intended goals and the assessment of their value by the programmes’ stakeholders (Guskey, 2000). Here, several studies already looked into the goals and objectives of PDPs in general (e.g., Desimone, 2009; Garet et al., 2001; Smith & Gillespie, 2007). However, the goals for science PDPs and their perceived importance can vary (Astor-Jack et al., 2007; Luft & Hewson, 2014). Therefore, the goals of the programme should be further clarified at the beginning of an evaluation.

The defined goals should be meaningful to all stakeholders; therefore, the clarification should come from a group discussion. Here, a so called Delphi study is promising as it allows experts to be both anonymous and geographically dispersed, while still allowing them to deliberate on the opinion of the rest of the group (Osborne et al., 2003; Rowe & Wright, 1999). Specifically, experts answer several rounds of questionnaires that are interspersed with feedback, which allows for informed moves towards or away from the consensus of the group (Goldstein, 1975; Gupta & Clarke, 1996). As such, within a Delphi study risks of normative social influences that can negatively impact the validity of the study are reduced (Clayton, 2006; Osborne et al., 2003; Rowe & Wright, 1999).

Methodology

The stakeholders of CERN's TPs form a very heterogeneous and geographically dispersed group. Therefore, an internet-based three-round Delphi study was designed to elicit the views of the CERN's TP stakeholders. As the quality of the Delphi study relies greatly on the selection of the participating experts (Clayton, 2006; Powell, 2003), the stakeholders were invited to participate as experts in the study based on nominations and their qualifications. Ultimately, the experts formed five panels: (1) Physics education researchers with experience with PDPs, (2) CERN national TPs coordinators, who help organising CERN's national TPs, (3) Members of the CERN council and advisory boards with high knowledge of CERN, (4) Teachers, who participated in CERN's TPs in the past, and (5) Teachers, who have applied to participate in the future. The overall number of the participants by the panel and by round are presented in Table 1.

The first-round open-ended questionnaire gathered experts' opinions and ideas on what should be the goals, objectives, and design features of PDPs, both in general and at CERN. The responses were inductively thematically analysed. Here, the majority of the themes was created by grouping similar answers of the first 15 questionnaires. All questionnaires were then coded based on these themes, with the addition of several themes that appeared in later questionnaires. Finally, similar themes were grouped to form overarching categories. The results of the analysis were summarised and communicated to the participants, together with the invitation to the second-round questionnaire.

In the second round, the experts rated the themes on a six-point Likert-like importance scale, ranging from "Very unimportant" to "Very important". Here, the ratings of different themes and panels were compared using the Kruskal-Wallis test. Additionally, the experts were asked to comment on the existing themes' wording, add any missing themes, and comment on their rating. The comments were analysed to identify new themes and proposed changes in the wording of the existing themes.

Table 1. Experts in the three rounds of the Delphi study.

Panel	1st round	2nd round	3rd round
Physics education researchers	28	26	31
CERN national TP coordinators	24	20	14
CERN council and advisory boards	16	10	10
Teachers: past participants	13	28	17
Teachers: future participants	-	16	18
SUM	81	100	90

In the second round, the experts rated the themes on a six-point Likert-like importance scale, ranging from "Very unimportant" to "Very important". Here, the ratings of different themes and panels were compared using the Kruskal-Wallis test. Additionally, the experts were asked to comment on the existing themes' wording, add any missing themes, and comment on their rating. The comments were analysed to identify new themes and proposed changes in the wording of the existing themes.

The third-round questionnaire called for ranking of the themes within each category, again based on their importance. Here, the differences in the rankings between the panels were analysed using the concordance coefficient Kendall's W, while the differences between the ranks within the ranking were assessed by the Kruskal-Wallis test. Furthermore, for two categories, the experts were asked to distribute 40 hours between the themes, based on how many hours they think should be devoted to each of the themes in a 40-hour TP. Using the Spearman's rank correlation test, the level of correlation between the ranks and the hour assignment was determined. Additionally, the experts' comments on their ranking and the themes themselves were thematically analysed.

Preliminary results

The analysis of the first-round open-ended questionnaire resulted in eight overarching categories that are presented in Table 2. The categories included over one hundred themes. In the second round, the experts assessed the importance of the themes from the first round. Here, the analysis showed a ceiling effect, with more than 75 % of the experts rating nearly all themes as important. Additionally, the Kruskal-Wallis test showed no significant differences between the different themes and the different expert panels ($p>0.05$).

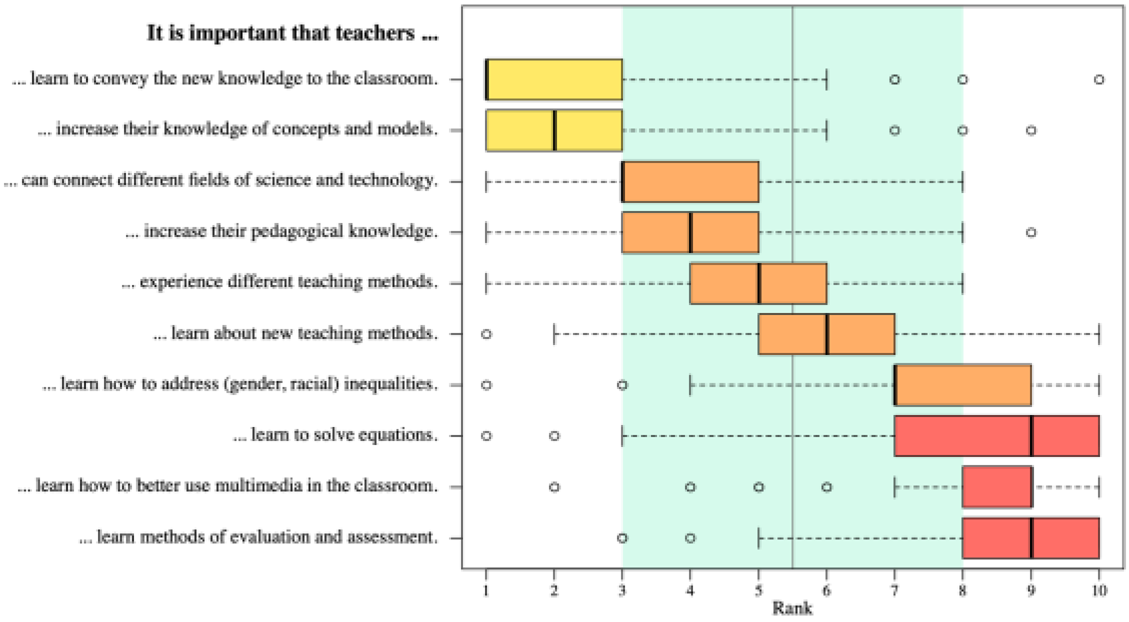
The results of the ranking in the third-round questionnaire showed good agreements between the panels, with Kendall's W above 0.6 in all categories. However, in most categories, the rank distances between separate themes were not significant. Therefore, the themes were grouped into three groups, based on their relative position of the theme median in comparison to the interquartile range (IQR) of the whole category, as shown on the example in Figure 1. Here, the themes with a median above the IQR are high ranking themes, themes inside the IQR are medium, and all below the IQR are low ranking themes. Additionally, the analysis showed strong correlations between the rankings and the assigned hours.

Table 2: Categories that emerged from the analysis of the first-round questionnaire, arranged based on whether they are connected to PDPs in general or to PDPs at CERN and other similar large research institutions.

PDPs …	**Category**
… in general	Goals and objectives
… at CERN and similar large research institutions	Learning goals
	Programme content
	Programme activities
	Follow-up activities
	Resources for teacher preparation
	Classroom resources
	Programme impact (on students, teachers, general public, curriculum)

Figure 1. Boxplot presentation of the overall ranking in the category “Learning goals”. The shaded area in the boxplot represents the overall interquartile range. The yellow, orange and red boxes show the high, medium, and low-ranking groups, respectively.

Here, the lower number on the rank axis corresponds to higher perceived importance.



Preliminary conclusions and discussions

Goals, objectives, and design features of PDPs are often mentioned in the literature, but rarely explicitly specified. This Delphi study compared the opinions of various stakeholders and provided a broad overview of what should be the goals, objectives, and design features of both PDPs in general and at CERN and other large research institutions. Specifically, the results show that the expectations of the different stakeholders do not differ significantly, despite their different backgrounds and roles in the PDPs. As such, this study provides a promising basis both for the evaluation of existing PDPs and the development of new PDPs.

Next step: Concept maps

According to Guskey (2000), the next step should be the design of an assessment method to assess the achievement of the goals. Based on the outcomes of the Delphi study, we started documenting participating teachers' conceptual understanding and the assessment of the development of their conceptual knowledge within the context of modern science and related to CERN. As there are no standardised tests in this field, a concept mapping technique was chosen as the main research method.

Concept maps are graphic organizers that represent the structure and evolution of knowledge frameworks through a hierarchical network of interlinked concepts (Novak & Cañas, 2008; Ruiz-Primo & Shavelson, 1996; West et al., 2002). Moreover, several studies found concept maps to be valid and reliable tools for assessing conceptual understanding and changes in concept and propositional structure over time (e.g. RuizPrimo & Shavelson, 1996).

Therefore, a pilot study was set up with three national and two international TPs using concept maps in a pre/post setting. Here, teachers were asked to create one concept map at the beginning and one at the end of the programme. In all cases, the concept-mapping technique was introduced through a presentation. Then, teachers were asked to construct a concept map to answer the focus question: “What do you want your students to know about CERN and particle physics?”. The pilot study led to promising results, indicating that teachers gained considerable conceptual knowledge during the respective TP. Based on these results, the main study data collection is planned to start in summer. Therefore, I will further discuss both the analysis and preliminary results of the pilot study in detail at the ESERA summer school. Here, I wish to receive feedback on the concept mapping study design and insight into the analysis of the concept maps. Indeed, I believe that participating in the ESERA summer school would be immensely helpful as I prepare for the main study and enter the third year of my doctoral research project.

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Environmental attitudes, environmental behavior and interest in nature in secondary school students: a cross-sectional study through grades 5 to 9

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Abstract

In the context of sustainable environmental education and environmental protection actions, the development of an environmental competence becomes increasingly important (BMB 2016, UNITED NATIONS 2015). Several Studies showed that an environmental competence consists of different environmental attitudes and behaviors (connectedness with nature or a general ecological behavior for example). In the current acceptation of the concept of environmental competence, the interest in nature is not included. With a cross-sectional study (grade 5-9, 10-15 years old, German secondary school, N = 1091, 51.4% girls), we investigated how the different attitudes and behaviors, including especially the interest of nature, vary among the different grades and how they relate to each other. In a general comment, we can say that all constructs (except the *Utilisation* one) decrease significantly over the grades 5 to 9. Further analysis about the correlations are currently conducted. Possible implications for science education research and environmental education will be presented and discussed at the summer school.

Problem and purpose of the study

In the field of Education for Sustainable Development, the teaching of environmental protection and its related environmental competence become increasingly relevant both at a national and an international level. In the Agenda 2030 (Sustainable Development Goals, SDG's), the United Nations declared that all learners must have the opportunity to acquire the knowledge and qualifications to promote sustainable development within the framework of the Education for Sustainable Development program (UNITED NATIONS 2015). Sustainable actions should then be integrated as a guiding and an interdisciplinary principle of education. With that approach, the notion of benefit of nature preservation and species conservation on our societies is transmitted to the students. All this approach involves ecological, economic and social aspects (MÖLLER & PASCH 2015). Students should be aware of the issues of climate change and environmental deregulation, so that they can spread their knowledge to all parts of society in the future (BMBF 2014, UNITED NATIONS 2015). The goal of this procedure is also to push students to have concrete and sustainable action. Several studies proved that an affective confrontation with nature during school lessons is particularly effective. Primary experiences in nature contribute to a better understanding of nature and, beyond that, to a higher environmental awareness and willingness to protect (e.g. STAROSTA 1991, BÖGEHOLZ 1999, LESKE & BÖGEHOLZ 2008, SCHÖNFELDER & BOGNER 2017).

The proenvironmental competence model according to ROCZEN et al. (2014) considers environmental attitudes, contrary to the simple acquisition of factual knowledge, as an intellectual precondition for environmental action. In order to improve target-oriented environmental behavior, these attitudes, as they have been proven to enable and motivate, must be analyzed (KAISER et al. 2008). The commitment to implement and achieve environmental actions is increasing with personal competences about the issue (KAISER & WILSON 2004). Being close to nature is one of the strongest motivations for environmentally friendly behavior. The relation between connectedness to nature and environmental behavior is primarily shaped by positive emotions acquired during experiences in nature. Then, those emotions influence environmental attitudes (KAISER et al. 2008).

Furthermore, Kals et al. 1999 describe in their model that emotional affinity toward nature and interest in nature can be traced back to experiences with nature. They also show that an interest in nature influences the willingness to protect it. It is therefore assumed that a lack of interest in nature leads to a loss of awareness of the ecological networks (including their effects) and makes it more difficult to build a connection between humans and nature (KALS et al. 1998). Taking all those facts into account, we consider that the interest in nature has an important predictor of the environmental competence. However, interest in nature is not taken into account in the proenvironmental competence model of Roczen et al. 2014.

Based on those facts, we want to investigate the different environmental attitudes and behaviors, as well as the interest in nature of students among different grades to see their variations. Although we know that some of the attitudes, like an attitude towards nature and a general ecological behavior, correlate to each other (Roczen et al. 2014), we want to find out how an interest in nature interacts with all these attitudes. In addition, several studies showed that the age has a big effect on some of the attitudes, such as ecological values or the interest in nature which is why we also took it as a variable. With those results, our objective is to provide new elements to science education research and environmental education.

Research Questions

1. How do different environmental attitudes like preservation and utilisation of natural resources, a connectedness to nature, willingness to protect nature, a general ecological and the interest in nature vary different grades (grade 5 to 9, ages 10-15)?

2. How does *interest in nature* relates to the other given environmental attitudes?

Research design and methods

In this work, we conducted a large scale cross-sectional study covering from grade 5 to 9, 10 to 15 years old children in German secondary schools (N=1091, 51,4% girls). We investigated on how the several environmental attitudes and behaviors, as well as the interest in nature differ from one grade to another. Data was collected with a paper pencil questionnaire (109 Items, 5-stages Likert scale) on affective nature aspects. The seven used scales were established from psychometric tests, which were also used in the two models described above: (a) Attitude towards Nature (BRÜGGER et al. 2011), (b) Connectedness with Nature (SCHULTZ 2002), (c) General ecological behavior (KAISER & WILSON 2004), (d) Ecological Values (Preservation and Utilization) (BOGNER & WISEMAN 1999, 2006), (e) Willingness to protect nature (adapted to KALS et al. 1998, LESKE 2009), (f) Interest in nature (NEUROHR & MÖLLER 2019), (g) Perceived responsibility towards nature (adapted to KALS et al. 1998, LESKE 2009).

Some of the scales had their item number reduced or adapted for the use in the grades 5 to 9. Using the methodology of parceling (LITTLE 2002), the items were reduced statistically after several steps to 18 of them per scale. By doing this reduction, we eliminated or at least mitigated disturbance variants, minimized scattering and errors, and enabled a similar normal distribution (BANDALOS & FINNEY 2001).

This adaptation was justified by a primary pilot phase (N=256) in different grades (5 - 9) with the original scales. The indices of item reliability, person reliability, construct validity, normal distribution and model fit for the different age groups were checked, attesting the test quality. Data analysis was conducted with Winsteps 3.74 and the statistic software program package (SPSS) 25.

Behaviors to protect nature are of normative relevance. Therefore, an examination of the influence of several socially desirable answering behaviors was included via an adapted social-desirable answering scale (Boehnke et al. 1986). An additional assessment of the sociodemographic variables (sex, age, educational level) was anonymously conducted to proved a description of the sample as well as to check the generalizability of the results on various subgroups.

Preliminary Findings

First of all, the Rasch analysis shows that all seven constructs have suitable quality. The

Rasch analysis operating (with indices like item infit MNSQ (.7 - 1.3), item reliability (.99), person reliability (.79 - .92) and item difficulty distribution) was used to evaluate reliability of persons and items as well as validity of the measurement instrument (BOONE et al. 2014).

All the constructs over the class levels 5 to 9 (except the *Utilisation* one) present a significant tendency to decrease. Significant differences don't occur at directly successive class grades (e.g. 5 and 6, 6 and 7), but they can be clearly observed when we compare to non following grades (e.g. 5 and 7, 7 and 9). The results show that with an increasing age, students not only become less interested in nature, but also feel less connected and less responsible for it.

To illustrate our the previous statement we can use the interest in nature scale. Interestingly, the interest in nature decrease significantly in general and between every grades ($p < .001$, t-test) except between grades 7 and 8 and 8 and 9 (the decrease is still insisting but not significant.

Furthermore, the correlation matrix (Spearman-Rho test) of the seven constructs shows medium to strong effects between the different constructs across all grades 5 to 9. Here, we find the strongest effects between the interest in nature and the connectedness with nature (.816) and between the willingness to protect nature and the interest in nature (. 754). In general, there is a strong correlation between nature interest and all other measured constructs. As a general observation we can say that all different constructs have a high level of effect to each other.

Based on the results, we assume that the different scales of the two models (Kals et al. 1999 and Roczen et al. 2014) correlate with each other and can thus be linked. The scales from both models show a decreasing expression with increasing age. It is therefore important to motivate young people in particular to act sustainably while they are becoming older. In this context, we have to consider the different scales of environmental competence and promote them in a targeted manner. We can only motivate young people to act in a sustainably way if we specifically foster an interest in nature, the connection to it or the attitude toward it.

More detailed results of the study will be presented and discussed at the Summer School.

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S-T-E-M Secondary In-Service Teacher Collaboration in Developing Integrated STEM Teaching

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Abstract

The present study aims to investigate in-service secondary teachers' views and practices on STEM integration during a collaborative STEM Professional Development programme. Participating in-service secondary teachers (n=26) from all four S-T-E-M disciplines (Science, Technology, Engineering, Mathematics) will work along with STEM academic personnel in groups through the design and development of STEM modules in a Learning Community (LC) framework. The process of developing the module and the discussions that will take place in LC meetings will be analysed through qualitative content analysis methods in order to trace potential similarities and differences on integration. The extent to which collaboration assists the design and development of the STEM module, as well as the level of integration applied will be analysed through network analysis. The impact that the primary discipline backround of the members as well as the network activity of the members has on the integration model implemented will be investigated.

Focus of the Study

Interdisciplinarity has a big impact in general education, since making interconnections between disciplines contributes to more meaningful learning (Kähkönen et al. 2016).

Despite the fact that the term "STEM Education" is been often used widely for "individual subjects (S-T-E-M), a stand-alone course or sequence of courses, activities involving any of the four areas, a STEM-related course or an interconnected or integrated program of study" (California Dept. of Education 2014), in our study, STEM Education is defined exclusively as "a teaching approach that integrates content and skills specific to Science, Technology, Engineering & Mathematics" (Martín-Páez et al. 2019, Toma & Greca 2018); therefore, is featured by nature as an interdisciplinary approach.

The two major foci of STEM Education that facilitate integration is real-world problemsolving and inquiry (Martín-Páez et al. 2019). Under this prism, the inclusion of complex problems concerning cutting-edge science topics, such as Nano-Science/Technology

(NST) provides the authentic framework that relates to students' everyday life and has justification for being studied from different disciplinary perspectives (Kähkönen et al. 2016), hence is recommended for STEM teaching approaches. However, teachers face difficulties in implementing integrated STEM teaching which incorporates problemsolving and inquiry, due to cognitive (Kelley & Knowles 2016) and attitudinal barriers (Toma & Greca 2018).

Collaborative STEM Professional Development (PD) programmes are considered necessary to support integrative STEM teaching through critical reflection and sharing of good STEM teaching practices (Kelley & Knowles 2016).

In addition, even when teachers implement integrated STEM teaching, diverse views of integration arise, resulting from their initial discipline backround and epistemologies (Ring-Wallen et al. 2018). As a result, several models of integration are being applied, as they put different emphasis and use on diverse S-T-E-M disciplines and different connecting relations between them.

Therefore, the present study aims to study teachers' views and practices on STEM integration in a Learning Community (LC) framework, consisting of S-T-E-M in-service secondary teachers and STEM Education academic personnel. Teachers along with STEM Education researchers will work collaboratively in the real-world complex field of NST both in synchronous and asynchronous ways through an online platform in order to design and develop STEM modules, i.e. interactive STEM artifacts and related STEM teaching material.

Furthermore, teachers' integration models, both from their point of view and through the process of design and development of STEM modules will be investigated. In order to trace similarities and differences on views and practices on integration in relation to their primary discipline assignment, teachers from all four S-T-E-M disciplines will participate in the LC and will cooperate in the design and development of the modules.

Literature review

Several calls stress the promotion of STEM Education in many recent educational reforms and international reports (NRC 2014). One of the basic arguments for promoting STEM Education is that real-world problems that students deal with in everyday life are interdisciplinary in nature as they relate to integrated knowledge and skills derived from multiple disciplines (NRC 2014). In order to tackle the complexity of real-world problems, integrated science teaching can create more meaningful learning of phenomena in contrast to theoretic simplifications used in monodisciplinary approaches (Kähkönen et al. 2016). STEM Education has the potential to improve students' content knowledge (Martín-Páez et al. 2019, Toma & Greca 2018), since students are supported to make connections between concepts with other concepts or broader issues and to understand potential conceptual conflicts between different disciplines (Kähkönen et al. 2016).

STEM education also affects students' attitudes towards science (Toma & Greca 2018) and aspire them to follow STEM careers (Beier et al. 2018).

The role of the teacher has far been stressed in the literature as crucial for STEM Education (Margot & Ketler 2019), i.e. his STEM knowledge and skills, his STEM teaching experience and attitudes. However, there is a lack of qualified STEM teachers and a respective lack of PD programmes in STEM Education. Teachers lack both STEM content knowledge and pedagogical knowledge to teach STEM (Ejiwale 2013), as well as inquiry experiences and hands-on instruction skills (Kelley & Knowles 2016). Furthermore, teachers consider integrated STEM teaching challenging (Margot & Ketler 2019) and tend to remain reluctant to make the shift to more integrative teaching approaches (Toma & Greca 2018).

Challenges also arise when teachers implement integrated STEM teaching, such as the fact that S-T-E-M disciplines are not given equal attention, as Science seems to prevail (Wong et al. 2016), whilst Mathematics are deemed difficult to integrate (Martín-Páez et al. 2019, NRC 2014) or merely used as a data analysis and a measurement tool (RingWallen et al. 2018, Tzanakis 2016). Similarly, in Mathematics Education, Physics merely appears as a possible context for Mathematics previously conceived abstractly, which does not imply the innermost relationship between the two disciplines (Tzanakis & Thomaidis 2000). Regarding Technology, it is also common not to integrate it in a meaningful way in terms of supporting learning of science content or address the engineering design challenge (Ring-Wallen et al. 2018).

On the other side, even though teachers' conceptions of integrated STEM play a significant role in what they design and implement in teaching practice, different perspectives from person to person on what integrated STEM means should be expected (Ring-Wallen et al. 2018). Several models of integration arise in the literature, starting from the following basic four models of Vasquez et al. (2013): a) disciplinary, in which concepts and skills are learned in silos, b) multidisciplinary, in which concepts and skills are learnt separately but within a common theme, c) interdisciplinary, where closely linked concepts and skills with the aim of deepening knowledge and skills and d) transdisciplinary, where concepts and skills from two or more disciplines are applied to real-world problems without reference to discipline boundaries. In a more analytical approach, Bybee (2013) proposed nine theoretic models of integration of S-T-E-M disciplines, whilst from a teacher point of view, Ring et al. (2017) presented eight teachergenerated models of integration, each of them consisting different discipline as "dominant" or starting point and different set of interconnections between disciplines. Collaboration plays an important role in STEM Education in order to create a common ground of understanding between members from diverse backrounds and expertise (Kähkönen et al. 2016) and to support the viability of STEM programmes in general (Margot & Ketler 2019). Several authors support co-teaching as a method to overcome individual difficulties in integrating S-T-E-M disciplines (Kähkönen et al. 2016) and the formulation of Learning Communities (LC), in which teachers from diverse backrounds and expertise can gain consciousness of the similarities and differences of concepts and skills from each discipline (Kelley & Knowles 2016) and support their integrated STEM training (Toma & Greca 2018). Critical discourse, reflection and sharing of good teaching practices in collaborative settings can contribute to building "discipline adequacy", i.e. a necessary amount of familiarity and understanding of the relevant discipline, as well as the cultivation of "soft skills", such as teamwork and leadership. Finally, through collaboration of members from diverse disciplines, potential incompatibilities and conflicts both in conceptual and in terminology/linguistic level can be identified and resolved and a shared understanding can be established (Kähkönen et al. 2016).

Research questions

Therefore, the research questions of the present study are:

- What different views of integration do in-service secondary teachers of the S-T-EM disciplines (Science, Technology, Engineering & Mathematics) have and what is the level of integration that they implement during the design and development of a STEM teaching module?
- To what extent does collaboration between teachers of different S-T-E-M disciplines affects their views and practices on integration?

Outline of the Research Design

The present study is in progress. 26 in-service secondary teachers (10 Science teachers, 5 Computer Science teachers, 6 Engineering teachers & 5 Mathematics teachers), form a LC in 4 sub-group LCs (5-7 teachers), in which there is at least one teacher from each ST-E-M discipline in each group. Group and sub-group discussions take place in both live in-person meetings, in synchronous online meetings through a teleconference platform and in asynchronous ways, using an online forum. The content area of the programme was chosen to be NST & NST applications, due to its interdisciplinary nature, since many different disciplines interfere in that field (Kähkönen et al. 2016).

The structure of the study consists of: a) an initial training phase in the fields of science content –NST and NST applications in K-12 education, b) a training phase of basic principles of STEM Education and STEM integration, c) a design and development of STEM modules phase d) an implementation phase, where teachers may use the developed STEM modules for teaching school students and e) a reflection phase.

Theoretical framework of the study is the Model of Educational Reconstruction for Teacher Education (ERTE) (Van Dijk & Kattman 2007), adapted to the needs of the present study. Therefore, studies concerning Pedagogical Content Knowledge, integrative STEM teaching and Collaborative Learning interact dynamically with the process of developing educationally reconstructed STEM learning environments from the teachers in order to develop educationally reconstructed STEM Teacher Education settings. Data will be collected from: a) transcripts of group discussions and reflections during the LC meetings from both synchronous and asynchronous ways through the online platform, b) the developed STEM modules including the designed STEM artefacts implemented in the module, both in its final form and during the design & development process. c) semiconstructed reflection interviews at the end of the programme about their views on integration and model of integration applied. Due to the explorative nature of the study, qualitative content analysis methods will be used (Mayring 2014). Discussions that will take place in the meetings along with the reflection interviews will be analysed and general patterns will be identified and coded in an inductive way in order to trace teachers' views about integration regarding their discipline backround, their skills and experience on STEM projects and their interaction in the network. Furthermore, in order to study the models of integration implemented, categories from Ring et al. (2017) will be applied in a deductive way. Concerning collaboration in group discussions, it will be studied using Network Analysis (Borgatti et al. 2018). Hence, interactions between peers will be coded and quantified and several network metrics, e.g. the density of the network, degree centrality & centralization of the members will be applied (Nipyrakis & Stavrou 2019).

Preliminary findings

The study is currently in the stage of data collection, which is expected to be finished by April 2020. Preliminary findings from the analysis will be presented by the time that the ESERA summer school will be held. It is expected that the diverse discipline content backround and discipline epistemologies that S-T-E-M teachers have will eventually impact to some extent their views about integration and the level of integration they implement in teaching. In addition, interactions in the group network will be studied from a discipline point of view. Finally, possible correlations between the network activity of the members and their views and practices of integration will be investigated.

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An investigation of student's conceptual understanding about cosmology through cluster analysis

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INTRODUCTION AND AIMS

Recent curriculum reforms in Italy have promoted the introduction at secondary school level of up-to-date physics topics, such as quantum mechanics, particles' standard model, the origin of the Universe and Cosmology. However, the implementation of such reforms has proven difficult, since such advanced subjects require a deep understanding of underlying physical mechanisms and theories. Cosmology is a meaningful context to teach contemporary physics topics, such as nuclear reactions, light spectra, redshift, and dark matter.

While students' beliefs and ideas about some aspects of Cosmology have been identified by prior work (Lightman et al., 1987; Lightman and Miller, 1989; Prather, Slater & Offerdahl, 2002; Hayes et al., 2011; Trouille et al., 2013; Wallace, Prather & Duncan, 2012), a coherent picture of students' conceptual understanding in this content area is yet to be provided. By identifying patterns amongst such beliefs and ideas, it would make possible to frame meaningful and more effective teaching activities to improve students' understanding of this content area. Therefore, the present study was guided by two research question:

1. What are the students' ideas about relevant conceptual aspects of Cosmology?
2. To what extent does cluster analysis allow to identify coherent patterns of understanding?

SHORT REVIEW OF LITERATURE

Modern physics should be more integrated into physics classes and, apparently, better approaches for teaching certain topics, such as cosmology, are needed.

Previous research studies indicate that many students (about 70%) are unaware that the Universe is expanding (Lightman et al., 1987; Lightman and Miller, 1989; Prather, Slater & Offerdahl, 2002) and think that matter as we know it existed also before the Big Bang (Lightman et al., 1987). Trouille et al.'s (2013) study also revealed some misconceptions, such as that the Big Bang theory concerns the creation of planets and/or the solar system or that the Universe has been always existing.

Prather et al. (2003) show that 42% of high school and 51% of college students regard the Big Bang theory as a theory describing the creation of the Universe; 24% in both groups think that the Big Bang theory describes the creation of planetary systems and furthermore, 29% and 42% respectively, believe that the Big Bang is an explosion of some kind.

In some cases, students struggle to read and interpret the Hertzsprung-Russell and Hubble's plots or confuse the definitions of galaxy and solar system (Hayes et al., 2011; Wallace et al., 2012).

The above results suggest that students may begin university courses in astrophysics with preexisting notions that may interfere with instructional efforts.

METHODS

Instrument

To answer our research question, we first identified, on the basis of previous studies and accepted scientific models of the Universe, seven conceptual dimensions that we deemed as important for a meaningful understanding of Cosmology (Prather et al., 2003; Bailey et al., 2012; Wallace, 2011; Trouille et al., 2013; Wallace, 2012). For the sake of clarity, these dimensions can be divided into two groups of concepts: “basic” and “advanced”. Basic concepts concern fundamental astronomical entities as stars, galaxies, constellations, and nebulae and the physical relationships between them. For instance, in this group, we include the notion that stars are formed from a nebula due to gravitational collapse, while galaxies are approximately selfgravitating systems formed by stars and nebulae and so on. Moreover, drawing on results in astronomy education (Rajpaul et al., 2018, Cole et al., 2018) we also considered as basic concepts the time and length scales of typical astronomical events and entities. For instance, we included in this group the notion that life appeared on Earth after the formation of solar systems and of our galaxy; similarly, we included the notion that the Sun is the closest star to Earth and that the centre of our galaxy is farther than the other galaxies. Advanced concepts include: the birth of the Universe; the Universe age and how we can estimate it (expansion rate, background radiation, etc.); how temperature and chemical composition of the Universe changed with time; the space-time expansion; hypothesis about the future evolution of the Universe. More advanced topics include also fundamental notions about black holes, dark matter and energy. For instance, we included in this group the notion that a black hole is an astronomical object characterized by its gravitational field.

Then, starting from previous work (Bailey et al., 2012; Coble et al. 2013a, b), we designed a written task with 17 open-ended questions that addressed two or more aspects of the identified dimensions, except for the first question that simply requested to define the term

"Universe". In Table 1, we summarize the correspondence between the conceptual dimensions and the designed questions. The questions included three types of task (see Table 2): written, drawing, and ranking. The reason for including also a drawing task was to link students' representations with the reasoning emerging from the written answer (Tytler et al., 2020). Ranking tasks were designed only for the age and distance of astronomical objects. The content validity of the questions was checked with three professional astrophysicists. Examples of the three types of task are reported in Table 2.

Table 1. Types of question

Type	Questions [a]	Examples
Written text	Q2, Q3, Q4, Q5, Q6, Q7, Q8, Q9, Q10, Q11, Q14, Q16, Q17	(Q2) What is the age of the Universe? (Trouille et al., 2013) (Q6) Describe what existed or occurred just before the Big Bang (Prather et al., 2003) (Q7) Describe what evidence you think supports the Big Bang theory (Q9) Explain, in as much detail as possible, what astronomers mean when they say ''the Universe is expanding'' (Wallace, 2011)
Drawings	Q5, Q9, Q10, Q11, Q14	(Q4) Plot how the temperature of the Universe changes over time (Q5) How would you describe the Big Bang with a drawing? (Q9) Using a schema or drawing, explain what you mean when you say ''the Universe is expanding" (Q10) Explain, using also a drawing, how the chemical composition of the Universe changes over time (Q11) Draw our galaxy and the sun's position
Ranking	Q12, Q13	(Q13) Rank the following celestial objects by their distance from the Earth's surface: cluster of galaxies, galaxies, Jupiter, the international space station, nebulae, Proxima Centauri, Sun, the center of our galaxy, Moon.

*Note that questions Q1 and Q15 were not analysed in this study.

Table 2. Distribution of questions across the conceptual dimensions of Cosmology.

Conceptual dimensions related to Universe		Acronym	Questions
Basic	Celestial objects and their relationships	CO	Q11, Q14a, Q14b, Q14c, Q14d
	Celestial objects age and distance	AD	Q12, Q13
Advanced	Universe age and its determination	AGE	Q2, Q3
	Birth of Universe	BB	Q5, Q6, Q7
	Universe temperature and composition	T&C	Q4, Q10
	Expansion and future evolution of Universe	EX	Q8, Q9
More advanced topics (e.g., black holes, dark matter)		BHDM	Q16a, Q16b, Q17

* Note that questions Q1 and Q15 were not analysed in this study.

Sample

We involved in this study a convenience sample of 432 high school students (17.9±0.7 years old). The students: (i) voluntarily attended, from February to May 2018, extra-curricular activities about physics topics at the authors' physics department; (ii) addressed basics elements of Astronomy during the first year of high school as part of Earth Science curriculum; (iii) were not involved in specific teaching-learning sequences or extra-curricular activities focused on Astrophysics.

Data Analysis

First, we categorized the students' responses using a constant comparative method (Strauss & Corbin, 1998). Three researchers analysed independently the whole data set generating for each question a suitable number of categories to fit the students' responses. Then, we collapsed the initial categories into five hierarchical macro-categories, ranging from "not given or unclear response" to "scientifically correct or acceptable", depending on the content of the question.

Two researchers reviewed again the students' responses to check the categorization. Inter-rater reliability was evaluated obtaining at the end of the process a satisfactory level of about 0.80.

Finally, because our sample was large and heterogeneous, we combined the students' responses on the questions related to the same aspect using cluster analysis (Fazio & Battaglia, 2018).

In such a way we could identify reasoning patterns corresponding to different levels of conceptual understanding about the targeted dimensions (Aldenderfer and Blashfield, 1984; Ammon et al., 2008).

Following the method used by Battaglia et al. (2019) we performed a non-hierarchical cluster analysis using the SPPS K-means algorithm. So the first step, starting from students answer categorization, is to construct a binary matrix (see Tab. 3).

Tab. 3. Data matrix. Each student *i* can be identified by an array a_i composed of *M* components *1* or *0*, where *1* means that the student used a given answering strategy to respond to a question and *0* means that they did not use it.

Question	Answer strategy	Student				
		S$_1$	S$_2$	S$_3$	...	S$_N$
Q1	AS$_1$	0	1	0	...	0
	AS$_2$	1	0	0	...	0
	AS$_3$	0	0	0	...	1
	AS$_4$	0	0	1	...	0
	AS$_5$	0	0	0	...	0
Q2	AS$_6$	0	1	1	...	0
	AS$_7$	1	0	0	...	0
	...	...	...	...	...	...
...	...	...	...	...	...	...
	...	...	...	...	...	...
Q17	ASM-1	1	0	0	...	1
	AS$_M$	0	1	0	...	0

We can define a distance starting by a modified form of Pearson's coefficient (Battaglia et al., 2019). The similarity between students *i* and *j* can be defined by choosing a metric to calculate the distance d_{ij}.

A formally correct application of this algorithm strictly requires the use of a Euclidean metric, that cannot be used for binary data. For this reason, it is necessary to transform the initial binary data. For this purpose, we used multidimensional scaling (Padraic Springuel et al., 2007). It consists in a linear transformation from an N-dimensional vector space to a two-dimensional one. Finally the SPPS k-means algorithm is applied on two-dimensional data.

The k-means algorithm has some points of weakness: (i) the *a priori* choice of the initial positions of the centroids; (ii) it is necessary to arbitrarily define the number q of clusters. This is resolved by repeating the clustering procedure for several values of the initial conditions and selecting those that lead to the minimum values of the distances between each centroid and the cluster elements (Loohach & Garg, 2012; Stewart et al., 2012).

In order to choose the number q of clusters to be initially used to perform the calculations, the silhouette function, S (Rouseeuw, 1987; Saxena, 2013). $S_i(q)$ gives a measure of how similar student i is to the other students in their own cluster. Subsequently, the values $S_i(q)$ can be averaged over each cluster k finding the values $<S(q)_i>_k$. Large values of $<S(q)_i>_k$ mean that (on average) cluster k elements are tightly arranged in the cluster and/or are clearly distinct with respect to elements of the other clusters.

PRELIMINARY FINDINGS

The final interpretation of each cluster was validated by the same professional astrophysicists, who had already checked the question validity. For each dimension, we found five clusters, which reflect increasingly complex reasoning about the concepts related to that dimension. The clusters are schematically described in Tables 4 and 5. Finally, we investigated the correlation between the knowledge of basic and advanced concepts. To this aim, we recoded the clusters for all dimensions into two categories: clusters characterized by scarce or incorrect knowledge (Clusters 1 and 2) were coded with 0, whereas clusters characterized by a partial/correct knowledge with some inconsistencies (cluster 3 to 5) were coded with 1. Finally, using crosstabs, we performed a chi-square analysis to see whether the knowledge about basic concepts may affect the knowledge about more advanced concepts about the Universe.

Table 4. Clustering of students' answers related to basic conceptual dimensions.

Concept	*Cluster*	*Description*	*%*
AD	1	Scarce or no knowledge about the topics	46.5
	2	Correct knowledge of recent and middle timeline, but they know only a near distance scale	16.0
	3	Correct knowledge of only recent timeline and of near and middle distance	15.7
	4	Correct knowledge of only recent timeline. Partially correct knowledge of celestial objects distances	12.1
	5	Correct knowledge of timeline and partially correct knowledge of celestial objects distances	9.7
CO	1	No knowledge about the topics	34.7
	2	No or incorrect definition of star and nebulae. They define the constellation generically as a group of stars, the nebulae as cluster of gas and the galaxies as set of celestial objects	27.1
	3	No or incorrect definition of constellation and nebulae. They define the star as an emitting light object and the galaxies as set of celestial objects	13.9
	4	No or incorrect definition of star. They define the constellation generically as a group of stars, the nebulae as cluster of gas and the galaxies as set of stars held together by gravitational force	10.2
	5	They define the constellation generically as a group of stars near each other, the star as an emitting light object with a reference to chemical composition or chemical reaction, the galaxies as set of celestial objects and nebulae as cluster of gas and dust	14.1

Table 5. Clustering of students' answers related to advanced conceptual dimensions.

	Cluster	*Description*	*%*
AGE	1	Scarce or no knowledge about the topics and no reference to how to estimate it.	10.4
	2	Scarce or no knowledge about the topics, generic reference to how to estimate its age.	5.6
	3	Student knows the order of magnitude of the age of Universe but they don't offer any explanation as to how to estimate it.	34.3
	4	Student knows the order of magnitude of the age of Universe and partial reference to how to estimate it.	31.2
	5	Correct estimate of age and partial reference to how to estimate it.	18.5
BB	1	Belief that the Big Bang is a terrestrial catastrophe and the Universe existed in some way before. Evidence cannot be obtained.	19.5
	2	Big Bang as an explosion of energy and matter, which existed in some way before. Some evidence is given but in an incorrect way.	20.8
	3	Big Bang as an explosion of energy and matter, there was nothing before. No reference to evidence.	27.3
	4	Big Bang as an explosion of energy and matter, there was nothing before. Incorrect or generic references to evidence are provided.	19.9
	5	Big Bang as an explosion generating the Universe, when before there was very dense matter and/or energy. Correct evidences are provided.	12.5
T&C	1	Scarce or no knowledge about the topics.	34.9
	2	Temperature increased, but no idea about composition.	42.6
	3	No idea about the temperature. Basic elements gave rise to the more complex ones.	3.5
	4	Changing temperature and basic elements with no evolution to more complex ones.	3.3
	5	Temperature decreases. Basic elements gave rise to the more complex ones.	15.7
EX	1	No idea about theories describing the future of the Universe and its expansion.	15.5
	2	Alternative/Non-scientific theories about the future of the Universe. No idea about expansion.	30.6
	3		9.5

		No idea about theories describing the future of the Universe. Expansion as an increase of distance between celestial objects.	
	4	There exist theories describing the future of the Universe with no details. Expansion as an increase of distance between celestial objects.	15.7
	5	Correct evidences about the future of the Universe are provided. Expansion as an increase of distance between celestial objects.	28.7
BHDME	1	No answer.	54.6
	2	No knowledge about dark matter and dark energy. Generic definition of black hole.	14.6
	3	No knowledge about dark matter and dark energy. A black hole is an object	15.7
	4	The student knows that dark matter and dark energy exist, but without any details. A black hole is an object with a strong gravitational force.	10.4
	5	Students give a correct definition of dark matter and dark energy. A black hole with a strong gravitational force	4.7

Overall, students in our sample have a scarce knowledge of both basic and advanced concepts. Concerning basic concepts, on average 40% of the students belong to the scarce or no knowledge cluster, while only 10% show a more correct knowledge. Specific difficulties concern: the definition of star and the role of gravity; how to correctly estimate the relative distance between Earth, Sun, planets and the centre of the galaxy. Concerning advanced topics, data show a more complex pattern, according to the chosen dimensions. While expansion and age of the Universe seem slightly more understood by students (about 40% belong to clusters characterized by a partial or correct knowledge), on the other hand, for the T&C dimension, two-thirds students show a very scarce knowledge. In particular, they have no idea about the variations of temperature and composition of the Universe. Also in the BB dimension, which is focused on topics that are taught since primary school, students show some difficulties. In particular, they consider the Big Bang as an explosion and are often unable to relate it with the birth of the Universe. Moreover, about half of the students think that the Universe has always existed, thus the Big Bang is viewed as a kind of catastrophe. This evidence also suggests a confusion between deep and geological time. To the same concern, the great majority of the students (about 90%) believe that the Big Bang involved an explosion of energy and matter. Furthermore, only few students were able to refer to experimental evidence supporting the Big Bang theory or the estimate of Universe age.

In Fig. 1, we report the correlation between the knowledge of basic and advanced dimensions.

Correlation is significant (I^2 = 9.162; df = 1; p = 0.002; Cramer' phi = 0.146), thus a scarce or generic (partial or correct) knowledge about basic concepts lead more likely to a scarce or generic (partial) knowledge about advanced concepts.

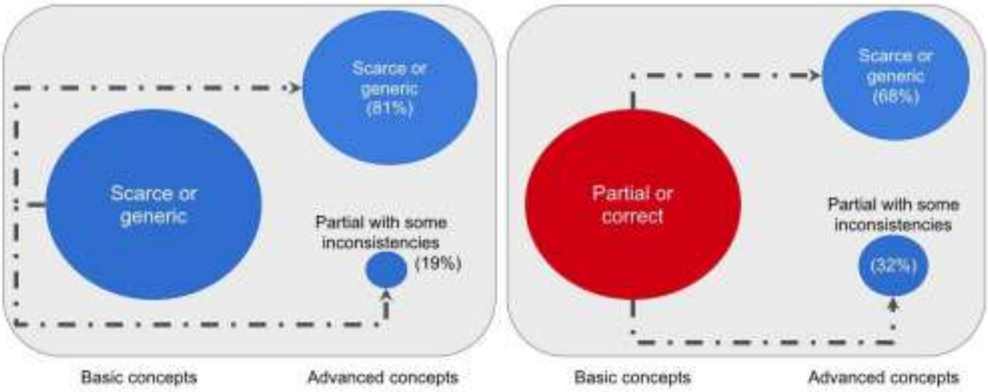

Figure 1. Correlation between basic and advanced topics knowledge.

DISCUSSION AND CONCLUSIONS

Our analysis reveals that the students' knowledge about the Universe is rather limited. While the collected students' responses suggest that Cosmology is addressed somehow during curricular teaching and dissemination activities in informal setting, results of the cluster analysis point out that some relevant aspects are neglected, for instance how scientists support claims about theories of the Universe.

Furthermore, curricular teaching seems to have a limited impact on students' ideas also about basic aspects such as: definition of stars, nebulae and galaxies, order of magnitude of distances between celestial objects, timeline of relevant events as the appearance of life on Earth and the formation of planets and stars, the role of gravity and other physical mechanisms (spectra, nuclear reactions).

Cluster analysis reveals also a fragmented knowledge about basic aspects in Cosmology. In particular, students found it difficult to relate the distance between celestial objects and the timeline of events. Regarding advanced dimensions, as expected, knowledge is on average scarce (about 30% in clusters 1 and 2, on average). On the other hand, a better understanding of the Universe birth, age, and expansion leads to a better understanding of concepts as a black hole.

In conclusion, our data suggest that typical high school teaching does not allow a deep conceptual understanding about Cosmology. To address this issue, we are also developing a teaching-learning sequence, which includes paper-and-pencil as well as laboratory activities.

To validate the identified clusters, we are in the process of administering a revised version of the questionnaire to a wider sample of students.

As next step of our research, we are identifying transversal patterns of reasoning strategies about the targeted topics. Furthemore, we will compare the results of clustering of different k-means algorithms in different computational environments (SPSS, R and Matlab).

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Pre-service primary teachers design and develop teaching modules on socioscientific issues related to nanotechnology

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Abstract

The integration of socioscientific issues (SSI) in science courses through contemporary scientific subjects is argued to increase students' motivation about science as well as to support students' decision-making on social dilemmas about scientific and technological innovations. However, teachers seem to face difficulties trying to incorporate the social dimensions of cutting edge research topics in their science lessons. Based on this, in the present work, we focus on the process of SSI teaching modules design and development relating to nanotechnology by six pre-service primary teachers. The main study is structured in 15 three – hours meetings. Initially, pre – service teachers get familiar with the scientific and the social aspects of nanotechnology and subsequently they design and develop a teaching module on SSI. Data for analysis consist of interviews, audiotapes of the meetings as well as the developed teaching module. Currently, we are at the data collection phase.

Focus of the Study

The rapid development of science and technology in contemporary society has given rise to a variety of global concerns such as environmental pollution, global warming, manufacturing via nanotechnologies etc. It is widely accepted that students, as future citizens, need to develop the abilities of argumentation and informed decision – making on complex, real-world problems related to such science and technology advances (Roberts, 2007). These abilities can be promoted in science lessons through the negotiation of Socioscientific Issues (SSI), which are open-ended, debatable problems that are subjected to multiple perspectives and solutions (Sadler & Zeidler, 2005). Cutting edge research topics are considered to enhance discussions on the social and humanistic implications of scientific and technological innovations given their inherent ambiguous and controversial nature (Levinson, 2006; Wan & Bi, 2019; Sadler et al., 2007). Particularly, the flourishing domains of nanoscience and nanotechnology (NST) set up such a cutting-edge research field that promises to have extensive implications for the entire society (Stavrou et al., 2018). The growing impact of nano – applications makes the need for education about risks, benefits, social and ethical issues related to NST an urgent issue for science education (Jones et al., 2013).

Despite of the educational significance of SSI and cutting edge research topics' societal implications for science education, the implementation of SSI approaches through contemporary scientific topics has been rather limited (Sadler et al., 2016). One reason is argued to be teachers' beliefs and difficulties (Lee & Yang, 2017). Research in science education indicates that teachers' beliefs, perceptions and their epistemological orientations influence their approaches to science teaching (Hodson, 2003). Therefore, it seems to be crucial the study of how SSI approach for contemporary scientific subjects is understood by pre service teachers and what their beliefs and orientations about SSI are. The resulting evidence could potentially support the design of strategies for pre service teacher education in order to encourage and enhance the SSI approaches during science courses (Porlán & Martín del Pozo, 2004).

Based on the above, and supporting the idea that science and technology are not only relevant topics to primary school, but also that their teaching from early childhood has the potential of enhancing students' high-order cognitive skills and expand children's scientific thinking (Eshach, 2006; Eshach, 2011; Zoller, 2011), the aim of our research is to investigate the process of SSI teaching modules design and development relating to NST by pre-service primary teachers**.**

Literature Review

SSI approaches have been positioned as a fundamental element of the scientific literacy because of the relevance of the issues with students' lived experiences and the opportunities they provide for engaging in dialogue surrounding science including the political and moral dilemmas of society. Particularly, various studies indicate that students' inquiry into SSI provides robust context for situating important science content and processes (e.g. Sadler et al., 2016). In addition to science content, SSIs also have the potential to serve as effective contexts for understanding the nature of science (e.g. Khishfe, 2017). Finally, educators have also rationalized the use of SSI in terms of their potential to foster students' argumentation skills (e.g. Zohar & Nemet, 2002).

Despite of the potentialities of SSI approaches for science education, it is difficult to identify tangible learning outcomes in SSI- based teaching (Sadler et al., 2007; Romine et al., 2017). That is why Sadler et al. (2007) have proposed *"socioscientific reasoning"* as a theoretical construct that includes practices associated with the negotiation of SSI. Particularly, these practices are: i. recognizing the inherent complexity of SSIs, ii. examining issues from multiple perspectives, iii. appreciating that SSIs are subject to ongoing inquiry and iv. exhibiting skepticism when presented potentially biased information.

NST is considered to be a suitable context for negotiating SSI and promoting the aforementioned practices in science lessons given its remarkable controversial applications (Jones et al., 2013). However, research into how teachers design and implement SSI activities through cutting edge research topics is still an emerging area, especially as far as primary teachers is concerned (Tidemand & Nielsen, 2017; Evagorou, 2011). A study on the SSI implementation by secondary teachers revealed that they follow a content-centered approach of SSI by using SSI as a motivation for students' engagement with the scientific content and by giving emphasis just on the assessment of content knowledge understanding (Tidemand & Nielsen, 2017).

Multiple models for SSI-based instruction have been proposed in the literature (e.g. Saunders & Rennie, 2013; Evagorou et al, 2015; Sadler et al, 2017) in order to support teachers in the development of SSI modules. Most models share common features such as: i. the use of a socially relevant issue as a focal issue, ii. the engagement of learners with science practices, disciplinary ideas, socioscientific reasoning practices, iii. the synthesis of the science and the social dimensions of the issue etc.

The social dimensions of an SSI are reflected in the social aspects of science as they are proposed by Erduran & Dagher (2014) in the Family Resemblance Approach about the nature of science. Specifically, the following social aspects of science: i. scientific ethos, ii. social values of science, iii. social organizations and interactions, iv. political power structures, v. financial systems and vi. professional activities & social organizations and interactions. These aspects can be used as axes for the discussion and analysis of SSIs given the fact that they represent the moral, political, social and economic concerns that are integrated and shape an SSI.

Research Questions

Based on the above, the present study focuses on the way pre-service primary teachers design and develop modules for the negotiation of current socioscientific issues raised by nanotechnology. Particularly, the research question of the study is the following:

How do pre-service primary teachers design and develop teaching modules on socioscientific issues arising by nanotechnology applications? The research question can be analyzed in the following sub-questions:

i. What are the aspects of socioscientific issues that pre - service primary teachers focus on while they develop SSI teaching modules about nanotechnology applications?

ii. What are the characteristics of the activities of the SSI modules that pre –service primary teachers design in order to promote students' socioscientific reasoning?

iii. What are the difficulties pre-service primary teachers face in designing and developing teaching modules on socioscientific issues about nanotechnology?

Methodology

The research framework of the present work is the Model of Educational Reconstruction (MER; Duit et al., 2012), a model that aims to bring science content structure and educational concerns into a balance when developing teaching and learning sequences. As our research concerns pre service primary teachers education, we mostly use a variation of the MER, as introduced by Van Dijk & Kattmann (2007), that serves as a model for designing guidelines for both pre-service and in-service teachers' education. The Educational Reconstruction for Teacher Education (ERTE) model (Figure 1) essentially incorporates aspects of the MER, as it interconnects the Design of teacher education with the Research on teachers' pedagogical content knowledge and with MER components.

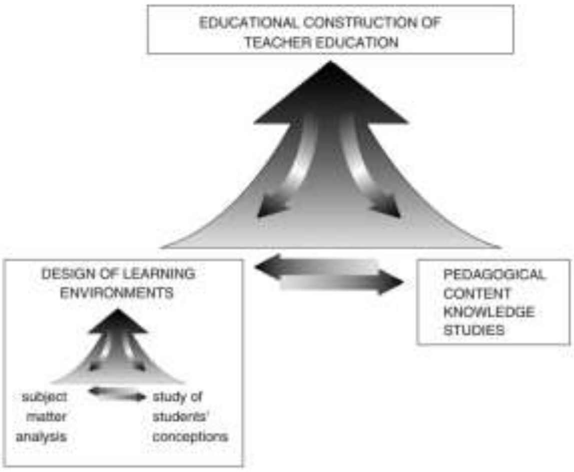

Figure 1. The ERTE model (Van Dijk & Kattmann, 2007)

Research Design

In order to deal with the research questions, a pilot study has been conducted and, based on the findings, a main study is taking place. In particular:

Pilot Study. The pilot study took place in the winter semester of 2018 – 2019. Twelve pre-service primary teachers participated in the investigation which was structured into twelve weekly three- hour meetings. The aim of the pilot study was to gain first insights into the way pre – service primary teachers develop science lessons about the social implications of the use of micro plastics. We chose to focus on the scientific topic of micro plastics given the fact that it is a contemporary topic with social and environmental implications that teachers are familiar with. During the first six meetings, pre – service primary teachers focused on i.

the scientific content of micro plastics and their potential risks, ii. the tentative nature of scientific knowledge and the inherent uncertainties of contemporary scientific topics and iii. the social aspects of the topic. The other six meetings were devoted to the design and development of a science lesson about the negotiation of the societal dimensions of micro plastics.

Main Study. Six pre – service primary teachers, who are at the last year of their studies, participate in the main study. The duration of the main study is nine months and is structured in 15 three – hours meetings, as it is illustrated in the Table 1.

Table 1. The procedure of the teaching module development

Phase of the Study	Meetings	Description
Phase 1	Meetings 1 - 5	Pre service teachers' familiarization with: • the scientific content of nanotechnology (1 meeting) • students' misconceptions about nanotechnology (1 meeting) • the tentative nature of scientific knowledge (1 meeting) • the social aspects of science (1 meeting)
Phase 2	Meeting 6 -10	Design & Development of the teaching module
Phase 3	Meetings 11 - 13	Implementation of the teaching module
Phase 4	Meetings 14 – 15	Reflection – Modifications on the teaching module

Currently, the phase 1 of the main study has been completed and we expect to have finished the empirical study before May 2020.

Particularly, phase 1 tried to deal with the challenges teachers face while addressing SSI in science courses. Therefore, initially, pre – service primary teachers got familiar with core scientific ideas of nanotechnology as well as with innovative applications of the discipline via inquiry based activities developed by our research team in the context of the European Union project "IRRESISTIBLE" (http://www.irresistible-project.eu/). Subsequently, pre-service primary teachers discussed about the uncertainties of contemporary scientific topics and the tentativeness of scientific knowledge in general through their engagement in a "mystery box" activity (Lederman & Abd-El-Khalick, 1998). Finally, pre – service primary teachers got familiar with the social aspect of science (Erduran & Dagher, 2014) and explore the societal implications of nanotechnology.

In phase 2 pre-service primary teachers will design and develop their teaching module. In phase 3 pre – service teachers will have the opportunity to implement and test their module with elementary students and at the last phase (phase 4) they will reflect on the whole procedure by suggesting modifications on their teaching module.

Data Collection

Data is collected using: a) an initial interview with the pre – service primary teachers in order to define their initial epistemological orientations and attitudes about SSI – based teaching, b) audiotapes of each meeting in order to define the progress in the approaches they choose to adopt as well as the aspects of SSI they focus on and c) the final teaching module. Additionally, at the end of the procedure a final interview will be conducted in order to clarify aspects of the design and development process.

Analysis

Due to the nature of the research and the small number of participants, qualitative methods of content analysis will be used (Mayring, 2015). Specifically, the category systems will be developed on the basis of the relevant literature and will be enriched or differentiated based on the new empirical data. So "the constant comparative method" will be followed, in which new empirical data is compared in iterative cycles with data that was collected in previous studies (Strauss & Corbin, 1990).

Concerning the data analysis, one idea is to focus on i. the approaches pre – service primary teachers adopt in their SSI teaching modules in order to promote students' socioscientific reasoning and ii. to define the role of the scientific content activities in the development of students' socioscientific reasoning.

Preliminary Findings

The findings of the pilot study showed that pre - service primary teachers developed content – centered teaching materials (Tidemand & Nielsen, 2017) although they included SSI activities. They used the SSI mainly as a motivation for students' engagement and the connection between scientific content and the SSI was fragmentary. For example, in a teaching module about micro-plastics and marine life, pre-service primary teachers engaged students by asking them to think about the consequences of plastics and microplastics in marine life based on an article written by a non - governmental organization and to comment on the different stakeholders that may have impact on the use of disposable plastics (e.g. industries, governments, citizens etc.). However, all the other activities of the module were related to the scientific content concerning micro - plastics such as bioaccumulation, plastic disintegration time, size of micro – plastics etc. without any other reference to the social dimensions of the issue.

We hope the data of the main study to give more insights into the interplay between the scientific and the societal dimension of a focal issue in the SSI teaching modules and into the way pre- service primary teachers promote this interplay in order to support students' socioscientific reasoning.

At the time of the summer school, I will have completed the data collection and I consider it as an opportunity to discuss and obtain feedback on the following analysis.

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Analysis of teacher-student interaction in the context of experimental workshops focusing on modelling for high school physics students

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Abstract

This doctoral research seeks to characterise teachers’ discursive strategies used to foster the progression of high-school students’ ideas for explaining phenomena in the context of modelling-based experimental workshops. Based on previous research (Williams & Clement, 2015), we associate discursive strategies with the phases of the modelling process to construct scientific models. In particular, we follow the Modelling Cycle (Couso & GarridoEspeja, 2017) to characterise what teaching strategies are used to promote that students use, express, evaluate and revise their own models of different physical phenomena. The final aim is to identify what discursive strategies are more helpful for promoting the progression of students’ ideas in model-based instruction.

Introduction

Beyond the importance that didactic design has in the students' learning process, teachers’ classroom discourse is crucial to the advancement of students’ ideas (Scott, Mortimer, & Aguiar, 2006; Williams & Clement, 2015). By making comments and asking questions teachers can motivate the development of students’ ideas (Kawalkar & Vijapurkar, 2013). This research seeks to characterize those discursive strategies that are useful for advancing students’ ideas in model-based instruction.

Theoretical Framework

According to the socio-cultural theory of learning, students’ learning could be understood as the result of their interaction and dialogue with the different actors involved in the classroom (Kawalkar & Vijapurkar, 2013; Mercer, 2010; Rojas-Drummond, Torreblanca, Pedraza, Vélez, & Guzmán, 2013). This interaction and dialogue should promote that students enunciate their initial ideas to motivate the argumentation and its negotiation that are necessary for the understanding of a phenomenon (Kelly, Crawford, & Green, 2001).

The role of teachers in this process of meaning-making is to support students appropriately (Kawalkar & Vijapurkar, 2013; Mercer, 2010). One way to do this is through questions or statements present in their discourse that are framed in **discursive strategies** which invite students to raise and develop their ideas. **Discursive strategies** are those teachers responsive strategies, included in a dialogue among teachers and students, that invite students to express, elaborate, question, debate, share, relate and institutionalize their ideas (Rojas-Drummond et al., 2013; Williams & Clement, 2015). Despite the importance of these discursive strategies, research shows that teachers need to incorporate them (Hennessy et al., 2016), as they usually lack knowledge on how to generate the sort of classroom discourse that promotes the development of students' ideas (Zembal-Saul et al., 2002).

We want to focus on those discursive strategies oriented to use, express, evaluate and revise the students' ideas from a model perspective. We will refer to a **model** as a representation of objects and/or phenomena, observable and unobservable, of sequences of events and ideas that allow us to understand the functioning of the world (Oh & Oh, 2011). Models and modelling-based instruction has largely been discussed as effective teaching and learning frameworks (Gilbert, 2004) within the epistemically rich scientific practices perspective (Osborne, 2014). From this approach, discursive strategies should support both the adequate progression of students' initial models towards those targeted in schooling and the students' rightful participation in the actual **modelling** practice, understood as the process of model construction.

Based on a previous research (Williams & Clement, 2015), it is possible to associate discursive strategies used by teachers with the phases followed in the process of constructing scientific models in the classroom. Following the synthesis of research on modelling phases of Couso and Garrido-Espeja (2017), we would like to identify the discursive strategies used by teachers to specifically promote that students' use, express, evaluate and revise their own models.

In relation to the scientific content, we will focus our attention on the discursive strategies that promote the progression of students' ideas about Newtonian mechanics (forces, movement and Newton's Laws), since they are contents of great relevance in secondary school but their understanding tends to be not very intuitive (Khiari, 2011).

Research context

The REVIR project developed in the laboratories of the Faculty of Science Education in the Autonomous University of Barcelona offers 4 hours long model-based inquiry workshops to secondary-school students from 12- to 17-years-old. The workshops have been iteratively designed by researchers in science education and are conducted in a computer-based teaching laboratory that has interactive whiteboards to support big-group discussions and

MBL sensors to collect and graph data at small group level. There are two expert teachers in each workshop, assisting both small and big group discussions.

This research has focused on the REVIR workshops on Newtonian mechanics "Study of the braking movement of a car" (https://ddd.uab.cat/record/182198) (here in after CB), and "Study of forces and energy in a bungee jump" (https://ddd.uab.cat/record/182192) (here in after BJ). The participants are secondary school student groups of twenty-five to thirty-five 15- and 16-years-olds, divided in small groups of three to five, from different high-schools.

Each of the workshops have an experimental set-up that tries to reproduce the phenomenon under study. In the case of the CB workshop, each small group study the braking of a toy car using a distance sensor. In the case of the BJ workshop, each small group study the fall of an object tied to a rubber band using a distance sensor.

Within a model and modelling-based approach, both workshops start by asking students for their initial model by drawing the forces acting upon the studied bodies and by justifying their prediction of the position-vs-time graph. Along the workshop, both the teachers' discourse and the experimental activities are addressed to guide the progression of these initial models towards more sophisticated ones, via their expression and use in predictions, testing via experiments and revision via whole-class discussions, among others.

Research question

We attempt to identify and characterize teachers' discursive strategies in a model-based instruction context. Our research questions are:

1) What discursive strategies are used by secondary-school expert teachers in a model-based instructional context?

2) How do these discursive strategies influence on the modelling practices in which students participate throughout the dialogue?

Methodology

This research has a qualitative approach and uses discourse analysis as an analytical framework (Gee, 1999).

During the months of January and February of the 2019 academic year, data collection through audio and video-recording was piloted in the CB and BJ workshops. The focus of the data collection was on capturing both teachers' discourse within whole-class and smallgroup discussions. Two workshops were transcribed, selecting those pieces of discussion among the teacher and students that we perceive to be productive for the progression of the students' ideas. Then, these episodes were doubled-coded, coding separately teachers' discourse in terms of discursive strategies and the students' discourse in terms of the level of sophistication of their ideas to explain the studied phenomena.

In order to build a category system that would characterize the discursive strategies of the teachers' discourse, we have followed a combined analytical approach of both deductive based on previous literature such as: Hennessy et al. (2016), Kawalkar and Vijapurkar, (2013), Roca, Márquez and Sanmartí (2012), Ruiz-Primo and Furtak (2007), Williams and Clement (2015), and inductive (based on our data) nature. This top-down/bottom-up process has allowed the construction of 15 categories of discursive strategies used by teachers to foster the sophistication of students' models. These categories were classified on 3 dimensions related to the intention of the teachers: to request, to contribute or to recover. In Table 1 we present the first draft of categorization. Some categories include examples to clarify its definition.

	Discursive strategy	Definition	Example
To request	Describing	To ask students to express their ideas through a descriptive question.	
	Conditional describing	To ask students to express their ideas through a descriptive question subject to a condition.	If I am an object, and right now a hole is made here and The Earth disappears, what would happen to me?
	Explaining	i. Implication: To ask students to express their ideas through an implication question. ii. Causal: To ask students to express their ideas through a causal question.	i. And then, what happen at this point if the forces are equalized? ii. The one I receive downwards (weight), who makes it?

	Clarifying	To ask students to clarify a previous answer seeking to rectify it.	
	Detailing	To ask students for more detail of a previous answer.	
	Improving	To ask students to improve the language in order to reference an explanation.	Is the earth making any force on me? *[student's answer: The Earth is* ***holding*** *me].*
	Requesting counterexample	To ask students to request against question or dissenting example.	How can we affirm that the force does not stay in the car?
	Requesting evidence	To ask students to request evidence of empirical or mental experiment.	

To contribute	Giving expert vision	To contribute additional information for understand an idea.	
	Giving details	To contribute details to the model intended to be developed.	Is the length of the arrow representing the tension always the same while the jumper is going down?
	Giving counterexample	To contribute a new idea that has not appeared so far, with the aim of contrast with other ones.	If you were to throw something upwards, while it is flying, should not there be a force upwards?

	Giving evidence	To contribute empirical evidence or mental experiment to justify an idea.	
To recover	Countering	To recover an idea that has appeared before, with the aim of contrasting it with the ideas that are being expressed at the moment.	
	Orienting	To recover an idea that has appeared before, with the aim of reorient the discussion, structuring it and reflecting on it, to give it a global meaning.	But we are representing when the car is running. Not when it starts, but when it is already running.
	Concluding	To recover an idea that has appeared before, with the aim of concluding, summarizing and closing the educator's discourse.	If it is not a force that is carried by the car that allows it to move, what is it that allows the car to keep moving?

Table 1*. Teachers' discursive strategies identified in the transcribed workshops.*

Initial results

Regarding research question 1, our initial categorization of discursive strategies of Table 1 is the first result of the research.

Regarding research question 2, we aim to relate the discursive strategies described in table 1 according to their role in fostering the students' modelling process. That is, according to whether they promote the use, expression, evaluation and revision of their models. At the moment we have identified some relations between some discursive strategies and some modelling practices. We have seen that the discursive strategy of both Describing and Conditional describing foster the Use and Expression of the students' ideas to explain the studied phenomena. For example, when the teacher asks *"If I take the hanging mass out of* *the car right now, what would its movement be like? Would it stop before it reaches the end of the track?".* Other relation is between the discursive strategies of Explaining-Causal and Clarifying in promoting the evaluation and revision of the students' ideas to explain the studied phenomena. For example, by asking: *How can it be that the car [in space] goes at a constant speed, if you have been told me that the car carries a force?*

Our intention is continuing analyzing other examples of teachers' discourse in other workshops to prove if the presented categories are enough to characterise these interventions. In relation to research question 2, we would like to continue the analysis for differentiate among discursive strategies that are more, or less, effective in promoting modelling process and the adequate sophistication of students' ideas.

In the following instances we pretend to characterise and describe the previous and subsequent instances that complement discussions among students and teachers, such as the dynamics established by students when trying to answer the workshop questions. We have perceived that questions and statements made by teachers, which are possible to characterise through the categories presented, are triggers of ideas that students have previously developed in group work, thus, also support of ideas that they will discuss in later instances in absence of teachers. Likewise, we will try to characterise the teachers' discourse according to their communicative approach (Scott, et al., 2006) when interacting with the students for complement the characterisation of the teachers' discourse.

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Design, implementation and evaluation of an inquiry training programme with physics and chemistry pre-service teachers

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Abstract

This study aims to design and to evaluate a training programme about inquiry-based science education (IBSE) specifically outlined for pre-service secondary science teachers (Physics and Chemistry). Our training design considers the conclusions found in the literature around a previous framework that has been shown adequately for this purpose. This framework integrates instruction in pedagogical content knowledge about IBSE with training to transfer to practice. Developing and using different instruments (such as questionnaires, researcher's journal, classroom observations or assessment rubrics, among others) we intend to examine the relevance and evolution of the IBSE views and practice of the future science teachers. Analysing among other aspects, the relationships between the beliefs of pre-service secondary science teachers and the processes of inquiry, we will try to give support in the design and implementation of IBSE activities for the high school classroom.

Keywords: pre-service secondary science teachers, inquiry-based science education (IBSE), training programme

Introduction

In recent years, one of the problems that most concern the community of researchers and teachers related to science education is the demotivation of students, which leads to a lack of interest in scientific culture as well as a lack of vocation either to practice as scientists or work in fields related to Science and Technology. The absence of connection between school science and the reality of young people (Gilbert, Bulte, & Pilot, 2011), as well as misinformation about the importance of science for a wide range of professions, is one of the factors causing detachment and undervaluation of students for science subjects.

The development of capacities and innovative ways to connect science with society is a priority in educational policies and programs. Making science more attractive to young people is directly related to the increase in social interest in innovation and the development of a higher number of research activities. Improving the scientific literacy of our society is, in fact, an ambitious goal, which can be achieved through the interaction of the different actors involved (educational system, university, teaching staff and students, museums and science centres or research organisations).

To address this problem, it is necessary to promote a renewal of science education, which advocates strengthening the application of content in diverse and relevant contexts for students (Fensham, 2009). Hence, only throughout methodological innovations, it will be possible to enhance the development of scientific competences and the increase of scientific vocations.

Therefore we consider it imperative to introduce the IBSE in the initial training of secondary science teachers and, in this sense, this Doctoral Thesis aims to design and to evaluate an IBSE training program specifically outlined for Physics and Chemistry preservice secondary science teachers.

Background

Following the main goals of the 21st science education, it is urgent to involve citizens as active agents of learning, through active methodologies that allow to identify and frame research problems, leading to the discovery of solutions and innovations that help place science in everyday life. Thus, European educational institutions highly recommend the use of such methodologies like inquiry-based teaching and learning in science education (IBSE) (Lederman, Lederman, & Antink, 2013). The richness and complexity associated to IBSE make it encompass a series of teaching strategies centred on students, which creates and reconstructs their learning socially by interaction with the environment (Lehman, George, Buchanan, & Rush, 2006).

Defined as a multifaceted activity “that requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations” (National Research Council [NRC], 1996, p. 23), the IBSE methodologies include the resolution of real and contextualised problems (Walker & Leary, 2009), as a teaching approach whose use it is extending in various university studies, and particularly in those related to the field of science.

However, its application in other levels of education is limited due to the difficulties that teachers find for their practice (increased workload, student opposition and greater responsibilities, among others) (Prince & Felder, 2007). Besides, the reduced application of IBSE methodologies in the classroom (Fitzgerald, Danaia, & McKinnon, 2017) is related to a whole series of teachers’ beliefs (Roehrig & Luft, 2004; Yoon & Kim, 2016). Since we are aware of the complexities in defining the concept “beliefs” (Mansour, 2009), in this work we will refer to it to characterize the teachers’ idiosyncratic unity of thoughts affecting their teaching practice. Particularly, we will consider both teachers’ content inquiry knowledge and self-efficacy beliefs as it refers to the ability to successfully perform a specific task, provoking a positive impact on student performance (McKeown, Abrams, Slattum, & Kirk, 2015).

Despite this struggling, the advantages of IBSE for the acquisition of scientific competence and the increase of scientific vocations (Kelly, 2008; Rodríguez, Allen, Harron, & Qadri, 2019) make it an active and necessary part of the initial teacher training programs. In general, those teachers who have experienced an inclusive and collaborative scientific education become true promoters and enthusiasts of inquiry learning, creating high expectations and transmitting the motivation for scientific learning (Clarke, Egan, Fletcher, & Ryan, 2006).

Research questions and objectives

Within this framework, we have considered the following research questions:

[I] What beliefs do the pre-service science teachers (PST) exhibit about the processes of inquiry before and after participating in a training programme?

[II] How can we help PST to design teaching activities that integrate real-life problems through the development of scientific inquiry practice and its practice? [III] What role can an IBSE training programme play in preparing PST to develop and improve the students' learning and interest in science?

To this aim, we define the following research objectives: 1) to analyse the relationships between the beliefs of PST and the processes of inquiry; 2) to design and perform a training programme for PST, aimed at integrating the development of scientific inquiry practices into the treatment of daily life problems, and 3) to analyse the impact of this training programme both on the teachers' beliefs about their content inquiry knowledge, and on their teaching efficacy and confidence to put it into practice.

We consider that linking both research on training and transfer to educational practice, not very present in the literature so far, could provide us with valuable information for the design of training programs on IBSE that have a more significant impact on educational practice.

Methodology

participants

This study involves a sample of 30 Physics and Chemistry pre-service teachers enrolled in a post-graduate master's degree compulsory for earning certification for secondary school teaching in Spain. We conducted the study during the second semester of this MEd, through the academic years 2018-2019 and 2019-2020. Each participant held a bachelor's or master's degree in either Science or Engineering and has no teaching experience at the moment the results were collected.

Instruments

We have initially designed a variety of instruments to collect relevant data:

- Questionnaire about pre-service science teachers' beliefs on IBSE (pre- and posttests), adapted from the MASCIL project (Maaß & Engeln, 2014).
- Emotions questionnaire, adapted from Jimenez-Liso et al. (2019), and designed to assess the emotions experienced by the PST during the training programme.
- Researcher's journal registering all the sessions of the training programme and PST classroom observation. The researcher took notes and digitally audio-recorded some of the sessions, which will be later transcribed for further analysis of data.
- PST productions (inquiry activities reports, keynotes and oral presentations).
- Assessment rubrics (products, teachers' and students' role).
- Students' final reports (student's journal on the implementation of inquiry activities and Master Thesis).
- IBSE training program evaluation survey.
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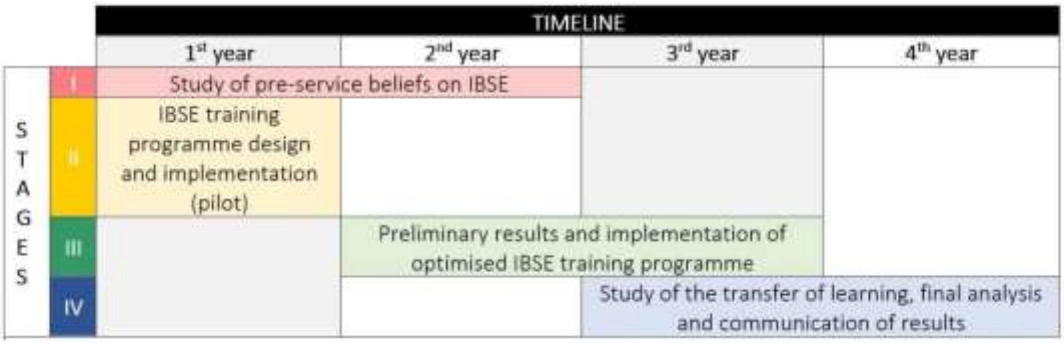
Following the research questions and goals above stated, our mixed-method study will involve the following stages (figure 1):



STAGES	TIMELINE 1st year	2nd year	3rd year	4th year
I	Study of pre-service beliefs on IBSE			
II	IBSE training programme design and implementation (pilot)			
III		Preliminary results and implementation of optimised IBSE training programme		
IV			Study of the transfer of learning, final analysis and communication of results	

Figure 1. Timeline of the research stages during the PhD

(i) <u>Study of the PST beliefs on IBSE</u>: a profound comparative study will be conducted using the pre/post-test methodology to analyse the beliefs and preconceptions of the pre-service teachers regarding the practice of IBSE in the science classroom.

(ii) <u>Designing and implementation of a pilot IBSE training programme:</u> this key stage consists in the development of a pilot proposal for an IBSE training programme (figure 2). For doing that, we have considered both PST beliefs and difficulties previously described in the literature (Akuma & Callaghan, 2019) as well as a preceding framework (España Ramos, Rueda Serón, & Blanco López, 2013) that integrates instruction in pedagogical content knowledge about IBSE with training to transfer to practice.

It includes a series of teaching materials specifically prepared (presentations, students' notebooks or experimental protocols). Throughout six class sessions of 90 minutes each, we develop the following aspects and content:

- *1st session.* Introduction to the training programme.
- *2nd session.* Reflection on the inquiry processes through the realization of an IBSE activity (A1) with the PST (student role).
- *3rd session.* Educational analysis (curriculum and teaching), also carrying out two analytical activities (A2 and A3)
- *4th session.* Exemplification of inquiry activities (teacher role), considering both the educational and the curricular elements involved.
- *5th session.* Design and evaluation of IBSE activities developed by the PST (A4).
- *6th session*. IBSE fair project carried out by PST through keynote presentations.

During the training programme, we will collect the data using the different instruments already detailed, at the moments specified in Figure 2. Additionally, a Q&A forum about IBSE will be available both online and "in-person".

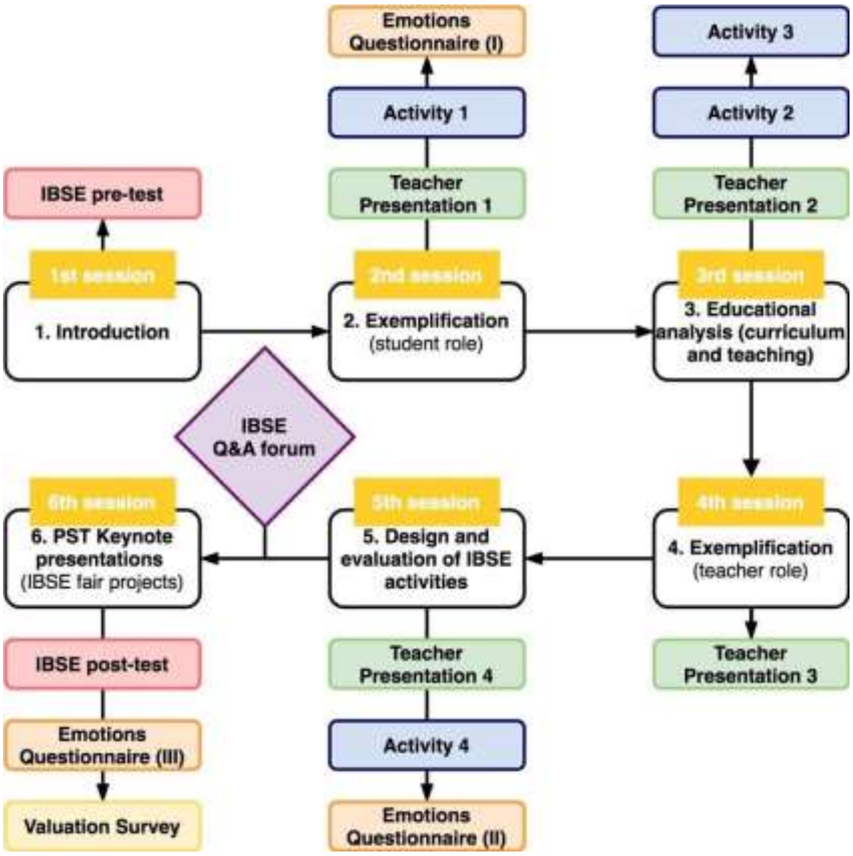


Figure 2. Structure of the IBSE training programme (pilot).

(iii) Analysis of preliminary results, optimisation and implementation of a new IBSE training programme version: the analysis of all the teaching materials and resources used, together with the PST productions will help us in the optimisation and further implementation of the IBSE training programme.

(iv) Study of the transfer of learning, conclusions and communication of results: once the training programme is accomplished (main study), and data and productions are collected, we will proceed to perform the study of the transfer of learning, mainly through in-depth analysis of the PST practical reports and Master Thesis and be able to establish final conclusions and relevant results about the impact of the programme.

Results and discussion

Preliminary results on the PST beliefs

Although still in an early stage, we have already quantitative and qualitatively analysed some of the results referring to pre/post questionnaires on the PST beliefs about IBSE. Consequently, we have identified the subsequent key points.

- We observe better teachers' perception of the importance of students designing their experiments/research to demonstrate their ideas, thus promoting their autonomy.

- There is also an increase in the conviction that the IBSE practice is effectively adequate to face both motivation and student learning problems, regardless of the students' academic profile exhibited.
- Also, results show greater self-confident about IBSE, reducing concerns about the fact that students may feel lost or frustrated or the difficulty of managing working collaboratively in groups, among other factors.

Furthermore, so far, we have identified individual relationships conditioned by demographic variables (gender, age) as well as others reliant on the research and teaching experience profiles of the sample of the PST participants. All these findings, together we the other data collected, will help us to optimise the IBSE training programme for the next implementation.

Preliminary results on the transfer of learning

We are currently carrying out the main study of the Master Thesis corresponding to the academic year 2019-2020, emphasising the transfer to the practice and the use of classroom observations during the pre-service science teachers' interventions at their practice centres.

Final considerations

Our research approach is regarded as a useful strategy to connect students with science, incorporating what we learnt from research in science education. The relationships that we can establish throughout the progress of our study, between the science pre-service teachers and their high school students, together with the creation of innovative resources and support tools will contribute to the improvement of the environment and learning outcomes, as well as to identify the weakness and strengths of our research.

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Science Identity Development of Female Students and Early-Career Researchers in Higher Education

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Abstract

This research project investigates women's science identity development in physics and physical sciences in higher education through a gender perspective. It arises from the real-life sociological issue of the low participation of women in science in Ireland, especially in the above-mentioned fields where the gender gap is the highest of all science disciplines, according to HEA reports of recent years.

Through using a case study approach with in-depth interviews this qualitative study aims to achieve an in-depth understanding of a gender - science issue through lived experiences of 29 women from undergraduate students to postdoctoral researchers in physics and physical sciences in 4 universities of Dublin. It focuses on their selfevaluation of science identities in relation to their gender and other social identities, self-identification with science, their expectations, and struggles.

The following questions were posed in order to deeply explore the science identity development of women from Feminist, Queer, and Intersectional theoretical perspective.

1. How do third-level female students and early career researchers in physics and physical science fields construct their science identity related to their gender identity?
2. What are the challenges faced by those women arising out of their gender-science identity interference?
3. Does women's movement in science report any influence in thinking of their science identity?
4.

The outcome of this study illustrates a variety of possible science identity constitutions of women both from an individual and collective identity perspective. This way, the result is expected to provide guidance on developing gender-sensitive and diversity-focused educational policies in science at the 3rd level particularly in Ireland where the research takes place. It also intends to promote further discussion about gender and science by engaging readers in critical reflections about their own engagement with science.

Keywords: women's representation, science, feminism, identity, higher education

Introduction

According to HEA National Review of Gender Equality in Irish Higher Education Institutions (2016) and HEA Statistics (2017/18), in the field of physics and physical sciences in Ireland where my research focuses, at each stage of scientific career ladder more men than women enroll, and more women than men leave the academic science at the highest level. HEA of Ireland has reported a larger gender gap in physics, maths and physical sciences in Ireland. This needs further analysis of gender issues within these disciplines.

This research aims to find out (1) how science identities of women, who are at early stages of their academic career path in physics and physical sciences, are developed and performed related to their gender identities along with their other social identities, (2) how they have developed a sense of belonging to science both individual and collective perspective and how does it impact on their advancement in academic science, (3) if they have experienced any struggles and challenges within these fields along with their coping strategies, (4) their evaluation of recent feminist movement in science and its influence on their science identity development Research Paradigm.

I situated this study within the constructivist and critical paradigm which involved collecting the stories of lived experiences of women and addressing the conflict, struggles, and power structures in these experiences. This study focused primarily on the following concepts and their inter-relationship:

- Science identity
- Gender identity (with other overlapping identities)

In the context of this research, identities are viewed to be both socially constructed and influenced by power relations within society and constituted in a social, cultural, and historical context. Science and gender identities of the women who participated in this study will be explored as related to self-belonging (emotional attachment) and a feeling of belonging to a scientific community (communal attachment). One learns how to be a scientist and to participate in that culture. This learning involves a process of cultural and historical production. Both ‘science’ and ‘gender’ identity along with roles associated with them have evolved throughout human history and are evolving through a period of one’s life. For this reason, I consider identity as a becoming process.

I situate my analysis within the non-essentialist perspective using a critical lens consistent with Butler's theory of performativity. From a performative perspective, identity is viewed to open to a continual process of transformation in this research. While the science and gender identities of women are explored in relation to self and social belonging, this study has also criticised the language, culture, and other social dynamics which ground identity categories as fixed and exclusionist

Theoretical Framework

This research theoretically is divided into 2 parts: Doing gender and doing science.
The 'doing gender' part has been developed in close association with my analysis of my participants' perception of their gender identities, gendered aspect of doing science, and the role of the feminist movement in science in shaping/empowering their science identities. Feminist, intersectional and queer theories presented here influence the entire research process from developing the research questions to the analysis of the interviews and presenting the results.

The 'doing science' part gives the readers a critical understanding of the social, historical, and linguistic factors behind the underrepresentation of women in science. Science takes place in a social and historical context. Therefore, understanding women's role in science from a historical and sociological perspective is crucial in order to discuss gender imbalance facing us today.

My theoretical perspective, to guide this research is Intersectional, Feminist, and Queer. The feminist lens applied in this study offers a critical perspective for understanding the gendered social order in the culture and philosophy of science focusing particularly on women's individual experiences.

"People have different experiences of what it feels like to be socially included or excluded, successful or subordinated, vocal or silenced" (Ramazanoglu et al, 2002). Influenced by Intersectionality, I aimed to see the picture from the unique location of the participants rather than generalise the individual experiences.

I expanded my theoretical approach to include Queer theory to challenge the normative social ordering of identities and subjectivities along a gender binary. In another word, I wish to use Queer theory to challenge fixed, restrictive, and binary societal norms, and to discuss its influences on shaping the science and gender identity of women involved in this study.

Research design

This research used an embedded single case study with semi-structured in-depth individual interviews which has facilitated a deep probing into the lived experiences of female physics and physical sciences students and researchers, and how they constitute their own identities in relation to these disciplines, their norms, and expectations.

In this study, investigation of ‘science identity’ development of women constitutes the main of analysis, while the influence of feminist movement on their science identity and the challenges experienced by women constitute the sub-units of analysis.

The boundaries of the case are geographical, temporal, and demographic: Geographically the case is bounded by 4 universities in Dublin: Trinity College Dublin, Dublin City University, University College Dublin, and Technological University Dublin. Specifically, TCD School of Physics, CRANN, AMBER and IGRAC Institutes, UCD School of Physics, DCU School of Physical Sciences, TU School of Physics, and FOCAS Institute are included. The disciplines of physics and physical sciences have been determined according to HEA 2017/18 statistics of the new entrance, enrolments, and graduates by level, the field of study, and gender.
My emphasis is on the women who are at an early stage of their careers because there are many leaks in the pipeline in this population according to the data report carried out by UNESCO (2015) which shows educational pipeline rates of women in science in Ireland. Also, according to a Study of Progression in Irish Higher Education (2014/15 to 2015/16), higher education dropouts and switching careers mostly happen in the early years of the education or career.

Demographically it includes women from different social backgrounds. My main aim is to capture diversity in order to see if they face any barriers in science based on multiple overlapping social identities. Temporarily, the case is bounded by the year 2019.
This study uses in-depth semi-structural individual interviews as its primary source, in which the participants tell their own stories with their own words. I chose to analyse the interviews one version of narrative analysis which deals with a discursive and performative dimension of the narrative as described in Taylor and Littleton (2006). Derived from discursive psychology, (Taylor et al, 2006) “meanings are constructed, carried and modified in talk and interaction”. I employed discursive narrative analysis for the following reasons: First, it focuses on the interactive context of the interview, performance of identity, and detailed examination of the talk. Secondly, discursive narrative analysis is in line with the theoretical perspective of this study. From a feminist perspective, I claim that women’s narratives are not only derived from their experiences but also, they are produced in social, historical, and

cultural context as well as by the teller's and listener's positioning. This way, discursive narrative analysis of women's experiences also has kept me alert to my role as a socially positioned listener of stories, and researcher in the interpretation of women's stories. One recent example of a case study of the relationship between science identity and a sense of belonging conducted in Ireland could be a study of Mooney et al (2018). They conducted mixed-method single case research to investigate the role that gender plays in deciding to study Computer Science at UCD. The study has revealed significantly lower levels of sense of belonging reported by female students providing a cause for concern considering the link of sense of belonging with progression in higher education and general well-being. This study is informative in terms of determining whether there is a difference in the sense of belonging between the genders. In the case of physics and physical science, my study looks at a similar issue from the broader sociological perspective by questioning the social norms which constitute 'woman' and 'scientist' as two opposite categories. This research specifically examined the role of feminism, gender, and other social identities on women's self-evaluation of their own science identity development focusing particularly on their sense of belonging, how they do science, and do gender.

Challenges

There are three challenges that I have come across during this research process: 1. definition of woman, 2. differences across the women, 3. the boundaries of "science" and "gender" identity, 4. interviewing with women (if I asked the right and meaningful questions or not), 5. My worldview too much interfering with the analysis and interpreting process. At this point, an intersectional and queer perspective has enabled me to recognize multiple forms of identity that can be read through discursive practices. Secondly, through the interviews, I realized that what it means to be a scientist and to be a woman is quite subjective. The boundaries of individual and collective identities of "scientist" and "woman" are discursively constituted and performed which, in other words, are always in process. In this study, I position identity primarily in relation to a sense of belonging and performances. And I acknowledge that both senses of belonging and performances may be fluid, relational, and depending on the particular situations.

The influence of post-feminist and Queer methodological principles that I follow, shapes the analysis, interpretation, and presentation process. This raised the questions of whether my participants shared the same feminist and Queer agenda and agreed with the outcomes of my research. Transparency and empathy are the two keywords to manage these issues throughout the entire research process. I tried to reflect the narratives from my participants' standpoints through my analytic interpretation rather than shaping the narratives from my worldview only

Throughout both the theoretical and practical (interviews) parts of this research process, I was more concerned about social norms, discourses, and roles that lead to social injustice and inequality in science. Through the interviews, I sometimes thought that what I was seeking to challenge may not be something that needs to be challenged from the participants' point views. Maybe these norms are so much naturalised and internalised that they have become a part of who we are. Questioning these norms may be like challenging a person's very self. For this reason, I tried not to ask questions which directly target their identities, instead, I referred to the power dynamics behind the "identity".

Conclusion

I simultaneously explored women's doing of science and doing of gender through their narratives. I particularly looked at how they view their gender and science identities as well as how these two identities affect each other. Even though women were influenced by the dominant idea of physics and physical sciences as being white and masculine they also challenged the dominant system of science identity by transforming it and by blurring the boundaries of what and who a scientist is. The process of constructing a science identity may lead to stress because science identity is not always consistent with 'women'. Criticizing the male stereotype of a scientist I realized women often broke this stereotype by trying to remove the clear borderline of 'scientist' and 'woman' through their everyday experiences. Their struggles and the challenge of the masculine structure of science are both individual and collective. They want to 'exist' and become 'visible' as who they are. They also do networking, collaboration, and sharing their experiences through the conferences, 'women in science' organizations and local events. It shows that their 'science identities' is an on-going process that is related to other particular identities, individuals, and the culture and practice of science.

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Computer simulations of complex systems: a study to understand the gap between experts and novices

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Abstract

Since the ‘50s, in all disciplines that deal with complex systems, computer simulations have progressively flanked theories and laboratory experiments, becoming the “third pillar of science”. Nowadays, even if they are at the core of complex issues, like climate change, on which policymakers and citizens have to make decisions, educational research has been highlighting strong difficulties for novices in understanding simulations and trusting their results. Our conjecture is that non-experts’ mistrust toward simulations is related with the difficulties in grasping the sense of the explanations produced by these epistemically opaque tools. The goal of our work is to investigate the nature of the novices-experts gap about the explanations based on simulations and their level of trust and to provide insights into the way this gap is addressed at the university level. To realize this objective, three studies with high-school students, professionals in simulations and university students have been designed.

Focus of the study

The role of computation, big data and machine learning is becoming pervasive in contemporary science. New concepts and methods have arisen and are leading to changes in how research is conducted and in how results have to be interpreted (Kitchin, 2014). These changes have impacted not only the scientific community but have reached the entire society. Despite the increasing societal relevance of these themes, the research literature in science education has stressed a widening gap between these scientific advancements and the knowledge of students and citizens about the methods of science (Jacobson & Wilensky, 2006). This constitutes a challenge for education since nowadays citizens are called to participate in social debates involving scientific themes (for example, climate change) and, often, to make responsible choices on them, but attitudes of mistrust have been observed. Our research study starts from this overarching problem and focuses on one of the main methods of contemporary science: computer simulations. After a review of the literature, the specific goal is to characterize the gap between novices and experts about their understanding of computer simulations of complex systems.

Research framework

Since the second half of the 20th century, computer simulations have progressively flanked theories and laboratory experiments, becoming the “third pillar of science” (Parisi, 2001). Their use has become widespread in all the disciplines that deal with complex systems, i.e. systems constituted of a set of elements which, interacting with each other and with the environment according to non-linear relationships, give the resulting systems some properties absent in the classical ones (Cilliers, 2007). The main traits of most complex systems can be summarized in the following list: i) non-linearity of the equations describing the macroscopic variables and of the rules for the local interactions among the agents; ii) high sensitivity to initial conditions or “butterfly effect”; iii) presence of feedback loops; iv) appearance of global properties that cannot be deterministically ascribed to the local rules which the individual agents obey but emerge from the self-organization of the system. Educational research has been highlighting strong difficulties in understanding simulations about complex systems because of their inner conceptual difficulties (Jacobson & Wilensky, 2006): indeed, they are comprised of multiple levels of organisation that often depend on local interactions in a non-linear way. Researches have shown that, when dealing with simulations of complex systems, novices often have difficulties in connecting phenomena occurring at the microlevel of agents with those occurred at the macrolevel (Penner, 2001). In particular, they struggle in identifying the “mid-level” between the single agent and the system that has been found to be relevant to foster sense-making (Levy & Wilensky, 2008). Regarding the explanations formulated about the complex phenomena, research has identified the reasons of novices’ difficulties in a “deterministic-centralized mindset” (Resnick, 1996). This is the preference for explanations that assume central control of the system rather than the emergence of behaviour from the local levels, and the neglection of the role of randomness in creating such phenomena. Further studies are showing sceptical attitudes and the tendency not to accept their results: novices rarely trust simulations as authentic scientific tools since they perceive them as artificial conjectures without any pertinence to real-world problems (Barelli, Branchetti, Tasquier, Albertazzi & Levrini, 2018). At the back of this study within our PhD research there is the conjecture that non-experts’ mistrust toward simulations is related with the difficulties in grasping the sense of the explanations produced by these epistemically opaque tools (Humphreys, 2008) that are neither mathematical demonstrations nor experimental tests. In order to explore and characterize this hypothesis, we investigate the scientific explanations elaborated on the basis of simulated complex phenomena. Within the science education community, great relevance has been ascribed to the issue of scientific explanation and many international educational frameworks recommend teaching this epistemic activity across all the school curricula (Osborne & Dillon, 2008). In science education research, various kinds of explanations have been individuated

(Braaten & Windschitl, 2011), starting from the explication, i.e. providing clarification for the meaning of something, to the different types of causal explanations (mechanistic, covering-law, teleological, intention-based) and statistical justifications.

Goal of the study and research questions

The goal of this work is to investigate the nature of the gap between novices and experts about their sense-making of simulated complex phenomena. In particular, we are interested in their: i) understanding of the static and dynamical elements (e.g. agents, rules, processes) of simulations; ii) explanations about simulated phenomena; iii) argumentations about the level of confidence about simulations. Moreover, we want to investigate how students and experts integrate, in their process of sense-making, three different layers: the layer of the physical phenomenon, its mathematical modelling, and the code implementation. In this sense, we intend to offer a contribution to the research framework by individuating, through a qualitative study, some of the possible reasons for the difficulties in recognizing simulations as authentic scientific tools, especially when they model complex systems. In order to obtain both a qualitative description of the novices-experts gap and insights into the transition to expertise, secondary school students with no previous background in complexity, experts in the field of simulations, and bachelor and master students in Physics and Mathematics are involved in the study.

To guide our analysis, we have formulated three research questions: RQ_1) What kinds of explanations do novices and experts make in coping with simulations of complex systems? RQ_2) What factors influence novices' and experts' argumentations about their level of trust on simulations? RQ_3) How do the three layers involved in the construction of a simulation (physical phenomenon, mathematical modelling, code implementation) interact in students' and experts' explanations about the complex simulated phenomena and in their argumentations about the level of trust?

Research design and methods

The research is articulated in three main levels: i) the design; ii) the implementation and data collection; iii) the data analysis. All the steps of data analysis are planned to be carried out with a qualitative strategy, through a theoretically-oriented iterative process of analysis and interpretation, where the hypotheses formulation is progressively refined through an enlargement of the empirical base, until theoretical saturation is reached (Anfara, Brown & Mangione, 2002; Denzin & Lincoln, 2005). To answer the RQs, the research plan includes studies with each target group (secondary-school students, experts, university students), each of them including a pilot. The overview of the plan of research is provided in Figure 1.

Figure 1. Research plan for the three target groups.

Study with secondary-school students

To answer RQ_s, we first needed to observe students when dealing with simulations. For the pilot study, we selected three different simulations of complex systems (respectively built on the basis of Schelling's model of segregation, Lotka-Volterra's model of predator-prey interaction, and global warming) and, in order to flesh out their specificities with respect to other didactical tools, an applet about a non-complex system (ideal gases). We prepared a protocol and performed semi-structured couple interviews. The interview protocol consisted of five sections, respectively designed to focus students' attention on:

i) the observation and the description of the "surface" of each simulation, identifying the fundamental elements represented and those in the background; ii) the explanation of the simulated phenomenon; iii) the meta-reflection about the meaning of explanation; iv) the relationship between the output of the simulation and the data obtainable from an experiment; v) their perception of trust in the use of simulation for addressing real-world problems. 26 volunteer students were involved in the pilot study, aged 17-18, from 5 different scientific lyceums in Emilia-Romagna (Italy) with no background in complex systems. To provide elements to answer to RQ_1, we identified linguistic markers to categorize students' explanations in the second section of the protocol on the basis of different a priori formulated explanations (explications vs different types of causal explanations). To contribute to respond to RQ_2, we analysed in particular the answers to the fifth part of the protocol, by identifying the epistemological issues behind their level of trust in simulations.

For the following study, that we are going to carry out in the first half of 2020, we are going to individually interview other 30 students of the same age. Indeed, during the pilot we found that, even if paired interviews allowed us to observe the rich interactions among students, they did not consent to obtain all the answers to the questions of the protocol for each simulation proposed. In order to provide answer to RQ_3, the interview protocol will be enriched with a section to show the students the code behind the simulation.

Study with experts

For the pilot study with experts, to complete the answer to RQ_1 and RQ_2, we have enriched the original protocol for the pilot with secondary-school students with questions designed to extract the expert domain-knowledge. It has been submitted, *via* individual interviews, to four categories of experts in the field. In the pilot study have been involved researchers and professionals in: i) modelling and design, ii) use for scientific research, iii) use for educational purposes and iv) epistemology of simulations. In total, 10 interviews have been carried out and the analysis, now at a preliminary stage, will allow us to flesh out the nature of expertise and current expert understanding about simulations and provide an insight on the nature of the existing expert-novice gap in terms of quality of explanations generated and attitude toward simulations.

For the following study, that we are going to carry out in 2020 from February to July, we are going to interview other 15 experts. As well as for the second-phase study with secondary-school students, the interview protocol will be enriched with a section about the layer of code behind the simulations.

Study with university students

In order to gain insights into the transition to expertise, our plan of research includes investigations involving university Physics and Mathematics students. The pilot study was carried out in the context of a course of Physics Teaching and involved 27 students. The survey consisted of three parts: i) a pre-questionnaire about students' knowledge about the terms “simulations” and “complexity”, ii) an introductory lesson about the specificities of computer simulations for analysing complex systems and iii) a focus group activity about the analysis of simulations. The focus group discussions were guided by the same protocol of the pilot with secondary-school students: their analysis will allow us to monitor the potential contribution of university curricula towards developing expertlike competencies.

The second-phase study is going to end in May 2020. The contexts are planned to be two courses of Physics Education, one mainly for bachelors and one mainly for master students. Both surveys will be articulated on the same three phases of the pilot, but interviews will be carried out at the end. The focus group and interview protocols will be revised so as to provide answer to RQ_3.

Data collection stages

At the date of our potential participation to the summer school, all the data will have been collected. In particular, we will have:

- 13 paired and 30 individual interviews with secondary-school students
- 25 individual interviews with experts
- 57 questionnaires, 12 focus groups and 15 individual interviews with university students.

Most of data were and will be collected in Italian, as the mother language of the most interviewees, but will be translated in English and made available for discussion with mentors and colleagues.

Preliminary findings

At the date of writing this proposal, an analysis has been performed only for the pilot with secondary-school students. The results have been published in (Barelli, Branchetti & Ravaioli, 2019). About RQ_1, even though most students successfully identified the mechanisms in each simulation, their explanations of complex simulated phenomena often consisted in mere explications; moreover, when explicitly asked if the simulations could provide any explanation about why the phenomena unfolded the way they did, some students answered that *“simulations just say how, not why”*. Only few students were able to go beyond mere explications, recurring to covering-law or teleological explanations that revealed assumptions in contrast with the complexity of the systems involved (e.g. explanations that assumed a centralized control, local-global linear inferences). Few mechanistic explanations were observed only when students reasoned about the noncomplex system of ideal gases. About RQ_2, we have pointed out that the factors influencing students’ lack of trust in simulations are not related to a lack of technical knowledge of the model laying behind the simulation but are merely epistemological. In particular, we noticed differences in the approaches of students with different backgrounds: students who had been taught science also from an epistemological perspective seemed more aware and able to critically evaluate the use of simulations; those with a weak awareness of epistemological issues, declared not to trust them at all, because of their naïve beliefs about the general meaning of model in science.

For the pilots with the other target groups the analysis is still at an early stage and will be accomplished by the date of our potential participation in the summer school.

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The role of academic emotions in science learning

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Abstract

Recent years, the importance of emotions on academic achievement and engagement has been widely acknowledged. However, little is known about the antecedents or the effects of academic emotions, or how they could be fostered in educational settings. Especially there is a lack of knowledge on the role emotions in the context of science education. This research consists of four separate but interrelated sub-studies, all aiming to clarify the role of emotions in science education. Studies 1 and 2 take place in a science classroom context, investigating situational aspects of emotions. Study 3 takes a micro level approach to study in-situ emotional responses to learning tasks. Study 4, in turn, is a longitudinal questionnaire study, enabling the investigation of causal relationship of emotions and learning. The results gained from this research provide new and valuable knowledge for (science) teachers, curriculum developers and other practitioners working on the field of education.

Outline of the study

In many developed countries, students' interest in science has been declining in recent years (e.g. OECD, 2016; Osborne & Dillon, 2008). This has been the case also in Finland, the context of this research. Furthermore, enjoyment, self-efficacy and the performance in science has decreased among Finnish students (OECD, 2016). Thus, more emphasis should be placed on developing such affect-aware learning environments that could promote students' interest and performance in science. So far, however, little is known about how students' positive emotions could be enhanced in practice. Further, there is a lack of knowledge on the dynamic interplay between emotions and learning occurring in the science classrooms. The aim of this study is thus to clarify the role of emotions in science education. The objective is to combine data from different educational levels and from versatile methods to obtain as comprehensive view of the phenomenon as possible.

Emotions that occur in educational settings or relate to learning, studying or other academic activities are defined as *academic emotions* (Pekrun, Muis, Frenzel, & Götz, 2018). Pekrun et al. (Pekrun et al., 2018) categorize academic emotions further to four groups based on their antecedents or objects of focus. *Achievement emotions* (such as shame or hope) relate to success or achievement in academic tasks. *Topic emotions* (such as disgust or feelings of empathy) relate to the specific topics studied in the class. Social emotions (such as envy or love) relate to social relationships in the class, for example between student and teacher or among peers. *Epistemic emotions* relate to learning itself, having an object focus in knowledge or knowledge construction. Epistemic emotions (enjoyment, anxiety, boredom, confusion, surprise, frustration and curiosity) typically occur in situations of contradictory or incongruous information, or when students' cognitive representations are questioned or new comprehensions are achieved (Pekrun et al., 2018).

Literature review

Previous studies have shown the importance of epistemic emotions in learning. For example, enjoyment and curiosity relate positively to learning, engagement and academic achievement (Gruber, Gelman, & Ranganath, 2014; Schneider et al., 2016). In turn, negative emotions such as boredom, anxiety and frustration have found to relate negatively to learning (Bosch & D'Mello, 2017; Chevrier, Muis, Trevors, Pekrun, & Sinatra, 2019; Pekrun, Hall, Goetz, & Perry, 2014; Schneider et al., 2016; Tze, Daniels, & Klassen, 2016). The role of some epistemic emotions is more complex. For example, confusion, in appropriate levels, can be beneficial for learning, but when unsolved can detract learning (D'Mello & Graesser, 2012; D'Mello, Lehman, Pekrun, & Graesser, 2014). Overall, confronting novel content or conceptual change often involves some emotional responses (Chiu, Chou, Wu, & Liaw, 2014).

Epistemic emotions often co-occur, correlate and interplay dynamically with each other. When encountering novel, even contradictory information, surprise is usually the primary emotion. Surprise is then usually followed by curiosity or confusion (Vogl, Pekrun, Murayama, & Loderer, 2019). If confusion is resolved, enjoyment follows.
However, if confusion persists, this may lead to frustration and eventually to boredom (D'Mello & Graesser, 2012). Confusion and frustration have also found to often cooccur (Bosch & D'Mello, 2017). Epistemic emotions in general, have found to originate to some extent from a person's epistemic beliefs and prior knowledge (Chevrier et al., 2019). Apart from this, little is known about the antecedents of epistemic emotions.

Instructional activities and teaching practices have an effect on how students think, feel and act in a classroom (Corso, Bundick, Quaglia, & Haywood, 2013). Previous research indicates that classroom activities emphasizing students' own active participation and knowledge-construction can promote interest and positive emotions (Inkinen et al., 2019; Juuti, Lavonen, Uitto, Byman, & Meisalo, 2010; Juuti & Lavonen, 2016). There is also evidence on personalized education increasing situational interest in classroom settings

(Reber, Canning, & Harackiewicz, 2018). On the other hand, complex learning often involves also more negative emotions of confusion, boredom and frustration (D'Mello & Graesser, 2012).

Previous studies on academic emotions have mainly used retrospective questionnaires to investigate the occurrence of emotions in educational settings (Goetz, Bieg, & Hall, 2016). Thus, little is known about the situational dimension of emotions in classrooms. Furthermore, contributions on trying to promote emotions in learning situations are mainly lacking. Also, longitudinal approaches trying to disentangle the causal relationships between affective and cognitive features are scarce.

Research questions

This research constitutes of four independent but interrelated sub-studies, all aiming to clarify the role of emotions in the context of science education. The research questions of the sub-studies are as follows:

- ✦ RQ1: How do instructional activities predict epistemic emotions in classroom settings?
- ✦ RQ2: What kind of emotional profiles do high school students have, and how do these profiles relate to learning gains?
- ✦ RQ3: How do the levels of epistemic emotions fluctuate during an intensive learning situation, and what are their roles in knowledge construction?
- ✦ RQ4: What is the causal relationship between academic emotions and learning?

Methods

The data for this PhD project is collected within two larger studies both focusing on student motivation, engagement and interest in the context of science education. The focus of this PhD project is specifically on academic emotions. This research, consisting of four interrelated sub-studies, exploits versatile methods and is implemented in multiple contexts. This gives a comprehensive view about the phenomenon being studied.

Study 1 takes place in Finnish upper secondary school physics classes. Data is gathered during six lesson learning units, where students (n = 100) learn mechanics inspired by the principles of project-based learning (Krajcik & Shin, 2014). To examine how instructional activities relate to situational emotions (RQ1), experience sampling method (ESM) and video observations are implemented. ESM data is collected from all the participants with mobile devices. Students fill out an ESM questionnaire based on signals coming to the smartphone randomly, three times per every lesson in the learning unit, however simultaneously for each student. To gain objective knowledge about the instructional activities in a classroom and thus investigate the contextual factors inducing epistemic emotions, the learning units of all participant classes are video recorded. Thematic analysis (Braun & Clarke, 2006) is conducted to categorize the activities found on the video. In the ESM data, the responses are nested within students. Thus, to explore the student-level relations in these nested data, the two-level regression analysis is used.

Study 2 is conducted in a similar context as study 1. Physics students (n = approx. 150) participate in 6 lesson learning units, where ESM data is gathered. Students' emotional profiles (RQ2) are studied through situational information acquired with ESM during the learning units. To assess students' learning gains, all students take a summative test before and after the learning unit. Latent profile analysis is conducted to evaluate the relations between the emotional profiles and learning outcomes.

Study 3 is based on an intensive learning situation conducted with high school students (n = approx. 40). In this study, students' situational emotions are examined while constructing knowledge (RQ3). The data is collected within a learning task conducted using an online form. In the form, students are shown videos on mechanics that are ought to be contradictory or non-intuitive for the students. Between the videos, students are asked to explain the phenomenon and to report their levels of academic emotions. In addition, these intensive learning situations are video recorded and further analyzed with the facial expression recognition program, the FaceReader (www.noldus.com), to get more comprehensive understanding about students' emotions during the learning task (Den Uyl & Van Kuilenburg, 2005). Temporal relations between emotions and knowledge construction are investigated with advanced statistical methods.

Study 4 takes a longitudinal perspective on the interplay of emotions and learning in the context of primary school science education. The aim of this study is to clarify the causal relationship between emotions and learning (RG4). This is done by implementing a questionnaire annually (from grade 1 to grade 6), through which information on students' skills in science and emotions is collected. Students (n = approx. 190) answer the questionnaire each spring semester as a part of their schoolwork. Time series analyzes will be conducted to examine the relation of the variables in question.

In all sub-studies of this research, the ethical standards of APA and the European Science Foundation (ESF) for good research and collaboration are followed. Student anonymity is carefully maintained and permission to perform the research is requested from school administrators and participating teachers. Informed consent is required from all the participants and the parents of participants under the age of 16. Participation is voluntary. Individual results of participating schools, teachers, or students will not be identified in the research reports. Furthermore, considerations have been made to implement the research in way that research activities and data collection in a school context would be pedagogical from students' viewpoint.

State of the research: data collected, analysis undertaken and preliminary findings so far

The data for the *Study 1* was collected in fall 2018 and spring 2019. The thematic analysis of the video data is nearing completion. However, the results based on preliminary classification of the video data already show that the level of epistemic emotions vary significantly during science lessons in respect of instructional activities. Especially introductory activities and demonstrations appear to be relevant activities in terms of inducing positive epistemic emotions such as excitement, surprise and curiosity.

The data for the *Study 2* was collected in fall 2019. The data collections and statistical analyzes will be completed during spring 2020.

The first data set for the *Study 3* was collected in fall 2019, and thus preliminary analyzes can be made during spring 2020. If needed, additional data will be gathered during year 2020.

Study 4 is a longitudinal study. Data collections started already in spring 2016, when the participating students were first graders (7 years old). So far, we have information on students' science skills, and hence learning, from four consecutive years. In spring 2019, we collected data also on students' emotions for the first time. Preliminary correlation analyzes suggest that science learning positively correlates to science related excitement and surprise, whereas it negatively correlates to science related anxiety and boredom. However, upcoming data collections are needed to examine the causalities of the variables. In spring 2020, the data will be collected from fifth graders, and the final data collection takes place in the last spring (2021) of primary school.

Overall, these preliminary results underline the importance of emotions in educational settings, and the complexity of the interplay of cognitive and affective features in learning situations. The upcoming data collections and analyzes are expected to complement and diversify the picture revealed so far, hence providing knowledge and tools to meet the demands of affect-aware learning environments.

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Understanding young people’s aspirations to become a secondary science teacher

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Abstract

In the context of teacher shortages disproportionately affecting the sciences, and a body of research relying on accounts of those already on teaching pathways, this longitudinal study considers how young people’s science teaching aspirations are formed and maintained, or abandoned, over time.

I use a mixed-methods approach including secondary analysis of survey and interview data from the ASPIRES studies, which have tracked young people’s science and career aspirations in England from primary school, through secondary school and into further and higher education.

This PhD will provide new knowledge on which factors, experiences and attitudes prompt some young people to want to become a science teacher, and which factors enable these aspirations to be realised, or dropped, as young people progress through education. I also consider how those pursuing non-teaching science careers view science teaching, and how these findings can inform efforts to reduce science teacher shortages in England and elsewhere.

Focus of Study

The current and projected teacher shortage in England remains an issue of considerable media, policy and academic concern. Data shows that, nationally, the ratio of school students to teachers has risen in recent years (Sibieta, 2018); something which has the potential to negatively impact students’ attainment and earnings later in life (Dustmann, Rajah, & van Soest, 2003). However, this issue is set to continue as student numbers are increasing (Sibieta, 2018), teacher retention is worsening (Sims, 2018), and teacher recruitment targets have recently been missed for the seventh year running (Department for Education, 2019).

The need for teachers is most acute at secondary level, and the sciences have some of the most chronic teacher shortages, with incentives and policies aimed at resolving this so far proving inconclusive (Sims, 2018). For example, only 43% of places on Physics teacher education courses were filled in the year 2019/20, compared to 127% of places for History teacher education (Department for Education, 2019). As a result, science subject specialism is suffering during a period when jobs in the sciences, technology, engineering and maths (STEM) in the UK are growing at more than six times the rate of overall employment (WISE, 2018).

The literature in this area focuses overwhelmingly on the attitudes, aspirations and motivations of *existing* teachers or those about to enter the profession. There is a distinct gap when it comes to investigating how young people come to form teaching aspirations over time, and decide whether or not they ultimately pursue teaching – especially in the sciences. The aim of this PhD is to contribute to addressing this gap by using longitudinal data to focus on the science teaching *aspirations* of young people, rather than the *motivations* of those already teaching or training to teach.

Literature Review

To date, only three UK studies are known to have collected data on the teaching aspirations of young people not yet pursuing a career, by surveying a population of students to understand whether or not they want to teach and why. Of these three, one only surveyed people at one university (Kyriacou & Coulthard, 2000), one only studied people who were undergraduates in geography (Unwin, 1990), and one was restricted to four institutions in one geographical area (See, 2004). Despite the obvious restrictions of these studies their findings provide evidence that those who are most likely to aspire to teach are those who identify as female, those who identify as White and those from families with lower than average socioeconomic status. This is supported by analyses of PISA data on the career expectations of young people (Han, 2018; Park & Byun, 2015), and data on the employment patterns of graduates (Chevalier, Dolton, & McIntosh, 2007), and reflects patterns in the make-up of the current teacher workforce in the UK (Department for Education, 2018) and other countries (OECD, 2005). There is also some evidence to suggest that the likelihood of a young person aspiring to teach is influenced by their attainment (e.g. Han, 2018), and their educational experience (e.g. See, 2004), as well as the wider societal status of teaching (e.g. Park & Byun, 2015), and teaching salaries (e.g. Chevalier et al., 2007).

Numerous studies have attempted to understand what shapes teaching aspirations by understanding the motivations of preservice teachers. However, in addition to only considering the views and experiences of those already on the pathway to teaching, these studies have tended to collect data from only one cohort of student teachers, from only one teacher education provider (Brookhart & Freeman, 1992). Furthermore, these studies have primarily used only quantitative methods; employing surveys requiring respondents to rate their motivations for teaching from a given, predetermined, list of influences. Much of this research is also atheoretical. The largest attempt to theorise the reasons why some people teach has been the development of the Factors Influencing Teaching Choice scale developed by Watt and Richardson (2007), which uses ‘expectancy value theory’. However, this focuses purely on psychological motivations rather than wider sociological factors, which evidence has shown is also strongly influential in the development of young people’s science and career aspirations (e.g. Archer et al., 2010). The limited scope of the existing research on preservice teacher motivations do not, therefore, allow for a detailed insight into the reasons why some people do, or do not, want to teach.

Some studies have focused on why some people want to become a science teacher specifically. Those that have are studies on preservice teachers which tend to focus on the wider specialisation of STEM, and provide a bleak outlook for those wishing to reverse science teacher shortages. For example, Tomšik and Cerešník’s (2017) study of preservice teachers in in the Slovak Republic found that those specialising in STEM shared a lack of interest and competence in teaching compared to their non-STEM teaching peers. And in the US Coppola et al. (2014) found that STEM undergraduates were more likely to want to teach only if they had the opportunity to develop pedagogical awareness and participate in informal teaching; things which are not routinely offered to those on a STEM pathway. Identifying whether or not those who aspire to teach science specifically are patterned by the same characteristics as those aspiring to teach other disciplines requires further research. However, recent OECD data from 19 countries showed that 59% of the science teachers surveyed, compared with 68% of non-science teachers, reported that they had chosen to become teachers by the end of secondary school; suggesting that those who go on to teach science may make their decision to teach later than their colleagues (OECD, 2019).
It is clear that we still do not know what shapes young people’s aspirations to become a science teacher. Notably, there is a lack of consideration for the role played by family, ethic and social backgrounds. Even less is known about why some young people who do want to become science teachers maintain or drop these goals over time – or what those pursuing science think of teaching as a profession, and whether and how this differs according to biology, chemistry or physics specialism. This study aims to provide such evidence, which could be used to inform efforts to increase science teacher recruitment amongst recent graduates.

Research Questions

My study seeks to answer the following questions;

1. What factors influence young people to want to become a teacher, especially at secondary science level?
2. What factors influence young people to abandon a teaching aspiration, especially at secondary science level?
3. How is science teaching viewed by those pursuing science non-teaching careers?

Data and Analysis

I am conducting new empirical research along with secondary analysis of data from the ASPIRES, ASPIRES2 and new ASPIRES3 studies, which track young people's science and career aspirations from primary school through secondary school and into further and higher education (from age 10 to age 23).

I will first conduct secondary analysis of the ASPIRES quantitative datasets, which contain aspirations data from approximately c.47,000 survey respondents from six different surveys. To do this I will manually code free-text responses to the question 'what would you like to be when you grow up?', asked in each survey, by using the four main teacher occupations according to the International Standard Classification of Occupations (2008) edition (ISCO-08) (International Labour Office, 2012). These are 1) general teacher, 2) primary teacher, 3) secondary teacher, and 4) special educational needs teacher. I will add an additional code for those who specified that they aspire to teach science, or a science discipline. I will also calculate the frequency of respondents who agreed or strongly agreed to the statement 'I would like to be a teacher or work with children' for each survey/age group where this was asked. I will then conduct crosstabulation analyses to provide breakdowns of those aspiring to teach from both the free-text and Likert scale responses by gender, ethnicity and social class, as these factors have been identified as influencing science and career aspirations in my literature review. These quantitative analyses will help identify patterns in who aspires to teach, and teach secondary science specifically, as well as whether there are similarities or differences between these two groups.

I will also conduct secondary analysis of the ASPIRES studies' qualitative dataset, comprising over 650 in-depth interviews conducted over 5 data collection cycles with c.61 students from ages 10 to 19. Specifically, all interviews from cohort members who expressed teaching aspirations will be analysed longitudinally using a Bourdieusian lens, in order to consider how students' social and family backgrounds and educational experiences played a part in their teaching aspirations. In spring 2020 I am conducting a pilot study using semi-structured interviews with 20 identified students, age 20/21, from the cohort who have previously expressed an interest in teaching to ascertain 1) whether the young person still aspires to become a teacher, and 2) what informed their decision to pursue/abandon their teaching aspiration.

Informed by my pilot study and themes identified from my secondary quantitative analyses, I will go on to collect new qualitative data from a sub-set of ASPIRES participants (tracked from age 10 throughout the three ASPIRES studies) who are 1) pursuing (science) teaching after consistently aspiring to be teachers, 2) not pursuing (science) teaching despite previously having teaching aspirations, or 3) science students not aspiring to teach.
This mixed-methods approach will enable me to understand both the breadth (from national surveys of young people) and depth (through interviews with young people as they form their ideas over time) of young people's science teaching aspirations over time.

Preliminary Findings

Initial secondary analyses of both the qualitative and quantitative datasets reveal a shortage of science teaching aspirations specifically, but also a shortage of general teaching aspirations, among young people.

From the 26 young people in the ASPIRES qualitative dataset who expressed an aspiration to teach at age 10, only three were still planning to pursue teaching at age 19, all of whom were young women who had consistently aspired to teach throughout secondary school, and none of them in science. All qualitative students who had previously reported aspiring to teach science went on to pursue other careers, most often in the sciences.

Initial secondary quantitative analyses indicates that around 34% of all secondary school students in the sample agreed or strongly agreed that they would like to teach or work with children. However, as respondents could respond positively to all options presented in this way, the data suggest that while teaching may be an option considered by many young people, it may not a common first choice of career. In contract, initial coding of free-text responses to survey questions on aspirations reveals that the percentage of young people who reported aspiring to be a teacher was consistently between 6% and 8% of respondents from age 10 to age 18. The level and consistency of this is somewhat promising. However, the proportion of those who aspired to teach science specifically was less than 0.5% of all respondents in all years, and less than 5% of all who aspired to teaching in all surveys.

I will be collecting additional qualitative data in spring 2020 and will therefore be able to share more emergent findings at the ESERA 2020 Summer School.

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Pedagogy of differentiated instruction in chemistry education: Impact and Evaluation

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- *View the poster here*

Abstract

Misconceptions in chemistry among high-school students can be a barrier to completing the learning and understanding process in the classroom, especially regarding heterogeneous classes. The purpose of this study is to research the development and activation of Customized Pedagogical Kits (CPKs), aiming at overcoming misconceptions found during classroom instruction, by incorporating diverse teaching strategies that meet individual student's needs. Using the pedagogy of differentiated instruction by implementing these kits should lead students to better understand chemical concepts, and might influence their self-efficacy beliefs and attitudes toward chemistry as well as attitudes toward differentiated teaching among teachers and high-school students in Israel. This is a mixed-methods study, mainly based on quantitative research tools and data analysis. It includes closed-ended questionnaires for teachers and students, a diagnostic task and an evaluation task for students. The study also incorporates qualitative tools: teacher and student interviews as well as observations in classrooms. The initial findings from the first two years of data collection show significant differences in self-efficacy, attitudes toward chemistry, and differentiated instruction, as well as students' achievements regarding misconceptions in chemistry contents, after implementing the customized pedagogical instruction kits.

Focus of the study

Many difficulties impede realizing the vision of quality differentiated chemistry teaching (Matuk, Linn & Eylon, 2015): (1) Chemistry is known to be a difficult subject to learn (Johnstone, 1991). (2) Many teachers adhere to traditional instruction methods (mostly frontal lectures) (Blonder & Mamlok-Naaman, 2019). (3) The teacher's inability to monitor closely in real time the state of the students' learning in crowded heterogeneous classrooms. (4) Considerable efforts are required for designing and implementing customized instruction programs to meet the students' individual needs despite class heterogeneity.

To address these difficulties, we have developed a set of 20 customized pedagogical kits

(CPKs) that cover the high-school chemistry curriculum. These CPKs use diagnostic tasks to support the teachers’ diagnosis of students’ understanding and a set of activities to address the different student misconceptions. Each kit contains: (1) a diagnostic task for a specific concept from the chemistry curriculum in order to find misconceptions among students. (2) A different pedagogical activities, each addressing a specific misconception. In addition (3) an evaluation task referring to the same specific chemistry concept, for evaluating the effect of the treatment. The kits also have a teacher’s guide that includes the specific pedagogical objective behind each of the kits’ components.

This model was inspired by the Response to Intervention (RTI) model used in special education. In this model, the comprehension and difficulties of special education students are continuously diagnosed and evaluated, to determine whether further intervention would lead to a better response to and comprehension of the learned contents (Speece & Case, 2001; Vaughn, Linan-Thompson, & Hickman-Davis, 2003).

The CPKs utilize a variety of differentiated teaching strategies to ensure that they meet the diverse needs of different students in a heterogeneous class. They were developed and refined in several stages that include selecting the chemical concept, scanning the literature as well as other data gathering to identify misconceptions, develop appropriate diagnostic task, develop appropriate treatment strategies and activities for each identified conception, review the CPKs by expert teachers and test them in class, and later improve them. More details about the process of the development were presented at the ESERA conference (Easa & Blonder, 2019). The purpose of the current study is to better understand the development of teachers' professionalism, attitudes and self-efficacy beliefs regarding differentiated instruction, and to formulate appropriate strategies for teaching chemistry. Furthermore, the study aims to better understand the impact of the CPKs on students' misconceptions, as well as their attitudes towards chemistry, personalized teaching, and diagnostics. We will examine those factors that influence teachers' self-efficacy in using (CPKs) regarding chemistry contents in the classroom, in addition to the factors that influence students' attitudes towards chemistry, and differentiated instruction in chemistry.

Review of the relevant literature

Research suggests that students are more successful when taught in ways that are responsive to their individual readiness levels (Vygotsky, 1978, 1986), interests (Csilcszentmihalyi, 1990; Maslow, 1962), learning profiles (Sternberg, Torff, & Grigorenlco, 1998), and motivational catalysts (Hertzberg, 1959). According to Vygotsky, students learn best when moderately challenged; thus, they should be instructed in their zones of proximal development, i.e., the range of learning between what is too easy and what is too difficult to accomplish.

Differentiation specifically responds to progress on the learning continuum and helps to bridge what students already know with what they need to learn (Heacox, 2002). "To differentiate instruction is to recognize students' varying background knowledge, readiness, language, preferences in learning, interests, and to react responsively" (Hall, 2002, p. 1). It requires flexibility in both teaching and expectations that drive instruction and allow for multiple sensemaking strategies. In some ways, differentiated instruction derives from the work of Dewey (1916), who advocated for the teacher’s instruction to be aligned with the students’ needs. It prepares students for democracy (Waterman, 2007), since it gives students responsibility for their own learning. Betts' (1946) work on differentiation, which focused on what he referred to as "differentiated guidance", was based on the belief that constant evaluation of individual strengths and weaknesses allowed progression through developmental stages. The idea of student choice is based on motivation research conducted by Deci and Jensen (1995), who found that students are intrinsically motivated if they have choices. Along similar lines, Bloom's (1994) six levels of higher thinking (knowledge, comprehension, application, analysis, evaluation, and synthesis) could also be embedded to ideas of differentiating instruction, since they encourage greater rigor for some students and variability among all.

When examining chemistry teaching in a heterogeneous classroom, additional challenges arise; chemistry is considered a difficult subject for many students because it contains many abstract concepts (Taber, 2002). These abstract concepts are important because their misunderstanding can inhibit and hinder the understanding of other chemistry concepts and theories (Zoller, 1990; Nakhleh, 1992; Ayas & Demirbaş, 1997; Coll & Treagust, Nicoll, 2001; 2001a).

The abstract dimension of chemistry, along with other software difficulties (such as a computational mathematical aspect), indicates that a chemistry class requires students to have a high-level skill set (Fensham, 1988; Zoller, 1990; Taber, 2002).
During the last four decades, many misconceptions and students’ difficulties in understanding chemical concepts have been analyzed. The following is a list of five examples of studies that have identified some misconceptions in chemistry learning:
The difficulty in distinguishing the concepts at the macroscopic, microscopic, and symbol levels in the context of structure and material linkage is typical and very common among chemistry learners (Bradley & Brand, 1985). These include difficulties in understanding the

concept of the mole (Gilbert & Watts, 1983), misconceptions in the atomic structure (Zoller, 1990 & Harrison Treagust, 1996), chemical change and radiation (Zoller, 1990; Abraham et al., 1992), and balancing oxidation equations and stoichiometry courtship (Zoller, 1990). These are selected examples, but other studies refer to misconceptions and difficulties in almost all the chemistry concepts commonly studied in high school.

Research has shown that addressing students' misconceptions by using differentiated instruction strategies, which are adapted to the students' learning needs and profiles, can help them to understand and learn successfully (Chen et al., 1975).

The current study accompanies and describes the implementation of the customized pedagogical kits (CPKs), which aim to overcome the students' misconceptions and difficulties in chemistry. This research will enable the chemistry education community to better understand the factors that influence the actual implementation of differentiation instruction in a chemistry class and to examine the impact of implementing these kits on students and teachers.

Main study questions

1. How, and to what extent, do the CPKs affect high-school chemistry students in the following aspects?

A. Misconceptions
B. Achievements in Chemistry
C. Self-efficacy beliefs
C. Attitudes towards chemistry and personalized instruction
D. Appreciation of the importance of chemistry

2. How, and to what extent, do the CPKs affect high-school chemistry teachers in the following aspects?

A. Teaching self-efficacy beliefs
B. Attitudes towards personalized instruction
C. Perception of their role in the classroom within personalized instruction

Methodology of the study

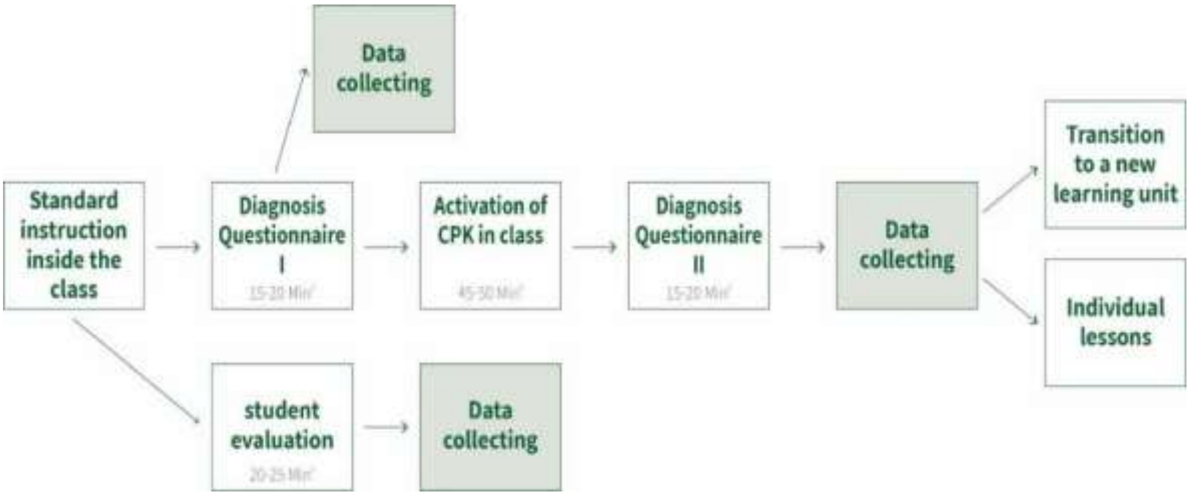
The current study is a mixed study that applies a model based on the Response to Intervention

(RTI) model used in special education. In this model, the comprehension and misconceptions of special education students are continuously diagnosed and evaluated, to determine further intervention that would lead to better response and comprehension of the learned contents (Speece & Case, 2001; Vaughn, Linan-Thompson, & Hickman-Davis, 2003).

Study design

The design of the study includes several stages (presented in Figure 1). Prior to the intervention, several students are interviewed and then the whole class fills out a pre-attitudes and self-efficacy questionnaire. Then the students are diagnosed by a diagnostic task in order to reveal their misconceptions of the chemistry content or concept. In the next lesson, the CPK is implemented to ameliorate their misconceptions by providing a nonconventional pedagogical activity for each misconception. In this stage, students work in groups and conduct the CPK activities in order to overcome their misconceptions and improve their understanding of the topic. A second interview with the same students is then conducted and the whole class fills out post-questionnaires. After a few days, the students are requested to respond to an evaluation task to determine the effect of CPK on their conceptual understanding. If they succeed to reach an appropriate scientific understanding of the concept, the teacher continues with his teaching. If some students still have misconceptions, the teacher helps them individually, as shown in Figure 1.

Figure 1: The intervention model



Study methods

This is a mixed-methods study, mainly based on quantitative research tools and data analysis; this includes closed-ended questionnaires for teachers and students, diagnostic tasks, and evaluation tasks for students. The study also incorporates qualitative tools, teacher and student interviews, and observations in classrooms, as described below:

1) A pre-post questionnaire for determining the attitudes and self-efficacy of chemistry teachers: a nine-point Likert scale (where 1 = not at all, 9 = to a large extent) questionnaire consisting of 45 items after factor analysis (27 items were omitted), with a reliability of 0.95.
2) A pre-post questionnaire for determining the attitudes and self-efficacy of students; it consists of 40 items after factor analysis (five items were omitted), measured on a five-point Likert scale (1 = not at all, 9 = to a large extent), with a reliability of 0.98.
3) Diagnostic tasks for students, which are given to them before the intervention.
4) Evaluation tasks given to students a few days after the end of the intervention, on subjects relevant to the intervention and on the misconceptions that were found using the diagnostic task. The grades are roughly on a scale of 100, which is known as achievement (pre-grade, post-grade).

In addition to the quantitative questionnaires, qualitative tools of pre-post students, teacher interviews, and classroom observations will be conducted and analyzed.

Study population

The research population includes high-school chemistry teachers (N=90) in Israel with five years of teaching experience and who have participated in a professional development programs offered by the Weizmann Institute of Science. The random, focused, and rolling sample consists of 9 teachers along with their students (N=150).

Data characteristics

Data collection so far has been through two different processes: one for data validation of the pre- and post-study questionnaires, by factor analysis and reliability after item dropout, which was done for 87 teachers (174 pre-post) and 114 students (228 pre-post). In the second data collection process, data was collected by pre- and post-questionnaires, and pre- and postinterviews of teachers and students; afterwards the customized pedagogical kits (CPKs) were implemented. These data were collected from 9 teachers and 150 students (300 pre-post), in addition to 14 pre- and post-teachers' interviews and 21 pre- and post-students' interviews.

Data collection was conducted within the first three years of the study; therefore, no further data collection is planned.

Data Analysis

The quantitative data from the questionnaires in the last three years of the study were validated and verified by factor analysis, as well as t-tests. The data will be further analyzed in the future, by regression and EQS analysis of the study model in order to determine the effect of the intervention and the implementation of the CPKs on the students and teachers. The qualitative data have not yet been analyzed; however, the data will be analyzed according to the Thematic Analysis method using text snippets and not just words and phrases in order not to lose the context in which different issues were communicated or carried out. The purpose of the analysis will be to arrive at an accurate and focused description and possibly to explain the relationship between the data. The analysis will be performed in four steps, according to Almond (2003), after unintentional analysis of the data during its collection:

A. Initial analysis: In-depth and repetitive reading of the text followed by a distribution of major themes - categories

B. Map Analysis: Searching for relationships between uploaded categories and hierarchical division by vertical arrangement that distinguishes between their levels (subcategories) and horizontal arrangement that classifies relationships into "super categories".

C. Focused Analysis: Identifying key categories that explain a wide variety of concepts and their relationships.

D. Theoretical Analysis: Rethinking the "category tree" and creating a theoretical explanation and a logical structure for the emergence of categories and their relationships.

I feel that by using my experience and knowledge in statistics and research methods, I will be able to complete the quantitative data analysis of the data. When attending summer school, I plan to focus on analyzing the qualitative data (namely, the student and teacher interviews and the class observations). At that point, I will finish the data collection stage and will have all the data in order to conduct the analysis.

Findings

Preliminary findings from the first two years of data collection show significant differences in self-efficacy, attitudes toward chemistry and personalized instruction, as well as students' achievements regarding misconceptions in chemistry contents, after implementing the CPKs (as shown in Tables 1 and 2)

Table 1: T-test results for independent means of self-efficacy in learning chemistry and determining attitudes toward personalized teaching of **students** over pre- and post-study periods. N=114, ***P<0.000

Variable	**Pre**		**post**		
df= 226	Mean	SD	Mean	SD	T
Attitudes towards importance of chemistry –AIC	18.0	2.5	26.0	2.1	27.3***
Students' attitudes toward personalized instruction in chemistry - APIC	24.0	3.2	36.5	3.2	31.9***
Self-efficacy in chemistry- SEC	12.3	1.9	18.0	1.7	23.1***
Students grades	79.213	21.185	88.493	15.579	***7.93

Table 2: T-test results for **teachers'** independent means of self-efficacy in teaching chemistry and their attitudes toward personalized teaching over pre- and post-study periods. N=87, ***P< 0.000

Variable	**Pre**		**post**		
df= 172	Mean	SD	Mean	SD	T
Self-Efficacy in Teaching Chemistry in differentiated class - SETCD	47.9	9.4	49.5	9.0	***23.4
Attitudes Towards Differentiated Instruction-ADI	54.8	7.4	62.8	8.2	***7.2

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Meaning-making Processes in Science within a Swedish Context: The Case of Newly-arrived Turkish Pupils in Sweden

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Abstract

Recently, educational institutions, especially in Europe, have received a growing number of newly-arrived pupils (Eurydice, 2019), which has attracted researchers to assess the educational attainment of these pupils. This research project hence aims to investigate meaning-making processes in the subject of Science where the learning process of newlyarrived Turkish pupils is scaffolded by their study-guidance teachers during studyguidance sessions. To outline the theoretical perspective of the research, Vygotsky's sociocultural theory on meaning-making and scaffolding is adopted. Data was collected through the observation of newly-arrived Turkish pupils and their study guidanceteachers during the study-guidance sessions. A piece of dialogue between a studyguidance teacher and a newly-arrived pupil has been presented to indicate the challenges which arise during scaffolded interactions.

Introduction

A newly-arrived pupil refers to one who has arrived from abroad, and has recently started his or her education in a new country (Eurydice, 2019). Each newly-arrived pupil arrives in a new country with their own native language, education history, and life experiences (Ojala, 2016). Unsurprisingly, they need to cope with the challenges of both developing content knowledge in a new language and adapting to sociocultural differences when they enter a new school system. Scholars have shown that the linguistic, cognitive, academic, and sociocultural development of pupils contributes to their integration into the adopted culture (Collier, 1995). Although pupils show these developments simultaneously, it generally takes at least four years for newly-arrived pupils to reach the same level of academic and language proficiency as native-speaker pupils (Collier,1995; Cummins, 2017).

Hence, to illuminate the development process of newly-arrived pupils in the subject of Science at the beginning of their education in a new country, this research project aims to investigate meaning-making processes during study-guidance sessions, where studyguidance teachers scaffold the development of newly-arrived Turkish pupils in the subject of Science.

Research questions:

- How do study-guidance teachers scaffold the meaning-making processes of newlyarrived Turkish pupils during study-guidance sessions?
- What characterizes meaning-making of scientific concepts by newly-arrived Turkish pupils?
- What semantic challenges arise during study guidance between the newly-arrived Turkish pupils and the study-guidance teachers?

Background Newly-arrived Pupils in Science Classes

In order to gain an understanding of how newly-arrived pupils develop their Science content knowledge alongside their native-speaker Swedish peers in Science classes, the use of scientific language is emphasized in this research project. Markic, Broggy & Childs (2013) stress that development of scientific language be delivered in the same way as foreign language instruction in order to achieve scientific knowledge. In the case of newly-arrived pupils, development of scientific knowledge is also dependent on the linguistic abilities of these pupils in the instruction language. One of the approaches that can contribute to the integration of these pupils into regular subject classes is Content and Language-integrated Learning (CLIL), which emphasizes Science teacher awareness about the idea that they are not only teaching Science, but also language. Nikula´s (2015) research on CLIL showed that teachers supported pupils through switching between everyday and scientific discourse, and also through giving pupils the opportunity to check the meaning of terms in their first-language during Science classes.

However, the degree of CLIL awareness of Science teachers may not be of sufficient assistance to the newly-arrived pupils in this research context. Ünsal et. al., (2016) and Karlson et. al., (2018) have stressed that pupils continue to struggle with both everyday and subject-related academic discourse. For example, Karlson et al. (2018) showed that pupils became confused when the word “flower” was translated from Swedish to the firstlanguage of the pupils as referring to the whole plant, whereas in scientific terms, “flower” refers to the reproductive organ of a plant. In this case, pupils may create a meaning of “flower”, which is not in line with the scientific definition.

Teaching Resources for Newly-arrived Pupils

In order to meet these challenges related to language and science learning, schools in Sweden supply resources, including study-guidance sessions. Newly-arrived pupils, such as those who participated in this research, are provided with study-guidance, during which the Turkish-speaking study-guidance teachers interpret the school subject, in this case Science, in the first-language of the pupils as a way to assist the learning of subjectspecific terms and concepts in Swedish (Ojala, 2016). Warren (2016) shows that the usage of multiple languages by pupils as a supportive tool in study-guidance sessions facilities their subject-specific knowledge development in their second-languages.

Theoretical Framework

This research is guided by Vygotsky's sociocultural theory, which claims that *"higher mental functioning in the individual derives from social life"* (Scott, 1998, p. 47). In particular this research is related to *meaning-making* and *scaffolding* within the context of study-guidance for newly-arrived pupils when learning Science. Within this theoretical perspective, learning is regarded as knowledge appropriation whereby individuals develop intellectual tools in collaboration and interaction with his or her peers, parents, etc. in a competent way, in certain contexts and cultures (Vygotsky, 1986). The intention of study-guidance sessions is for the newly-arrived pupils to be helped by their studyguidance teacher, who has more competence in the subject knowledge. Thus, sociocultural theory is considered as an appropriate point of departure for this research. The subsequent text reflects on meaning-making and scaffolding in the context of this research.

Meaning-making

Newly-arrived pupils might not be entirely successful in subject-specific learning in the early stage of their education in the new country, since they are unfamiliar with the new educational context. Ünsal et al. (2016) stress that the usage of scientific terms by Turkish pupils in their writing and speech did not match accurately with the scientific definitions of the concepts. Hence, hoping for newly-arrived pupils to learn the subject content seems at best highly optimistic. This research project therefore focuses on the meaning-making process of newly-arrived Turkish pupils in relation to the subject of Science during studyguidance sessions.

Meaning-making has been defined by researchers by drawing on Vygotsky's sociocultural theory. Accordingly, construction of meaning in its social context is formed by high-level cultural tools (Scott, 1998). In this research project, meanings made by pupils are considered as socially constructed and become visible when they express themselves through verbal language in a social-context.

Scaffolding as an Analytical Tool

Scaffolding will be examined to define the scope of its use as an analytical construal for this research. Perspectives on scaffolding are widely influenced by sociocultural theory, hence scaffolding is considered by researchers such as Wood et al. (1974) and Tang (2019) as a kind of assistance in the interactions between teacher and pupil.

It is crucial to expose what distinguishes scaffolding in study-guidance sessions from other types of help and in which cases interactions between study-guidance teachers and pupils can be counted as scaffolding. Scaffolding in this study is thus restricted to: assistance to pupils by teachers through interactions that enable pupils to make meaning of the subject of Science. Furthermore, it is assumed that scaffolding processes are not regulated solely through interaction between pupils and teachers, since scaffolding can be provided through multiple interactions among pupils, teachers, pictures, textbooks and so on. Scaffolding processes may also be manifested in gestures and body language as well as in verbal language, and scaffolding does not always lead to meaning-making (Holton & Clarke, 2006).
In order to aid initial analysis, six-dimensions of scaffolding are adopted from the research conducted by Maybin et al. (1992) as follows:

- The communicative support represents the type of talk, for example what kinds of questions are asked by the pupils.
- The learning object represents the learning entity concentrated on, for example concepts.
- The actions of teachers represent teacher activity regarding the learning object, for example their presentation of a new task.
- The actions of learners represent learner activity regarding the learning task, for example to use the teacher as a resource.
- The context represents, for example learning situations with everything which they entail socially and culturally.
- The outcome represents a practical demonstration of knowledge development, for example an indication of meaning-making in the dialogue between teacher and pupil.

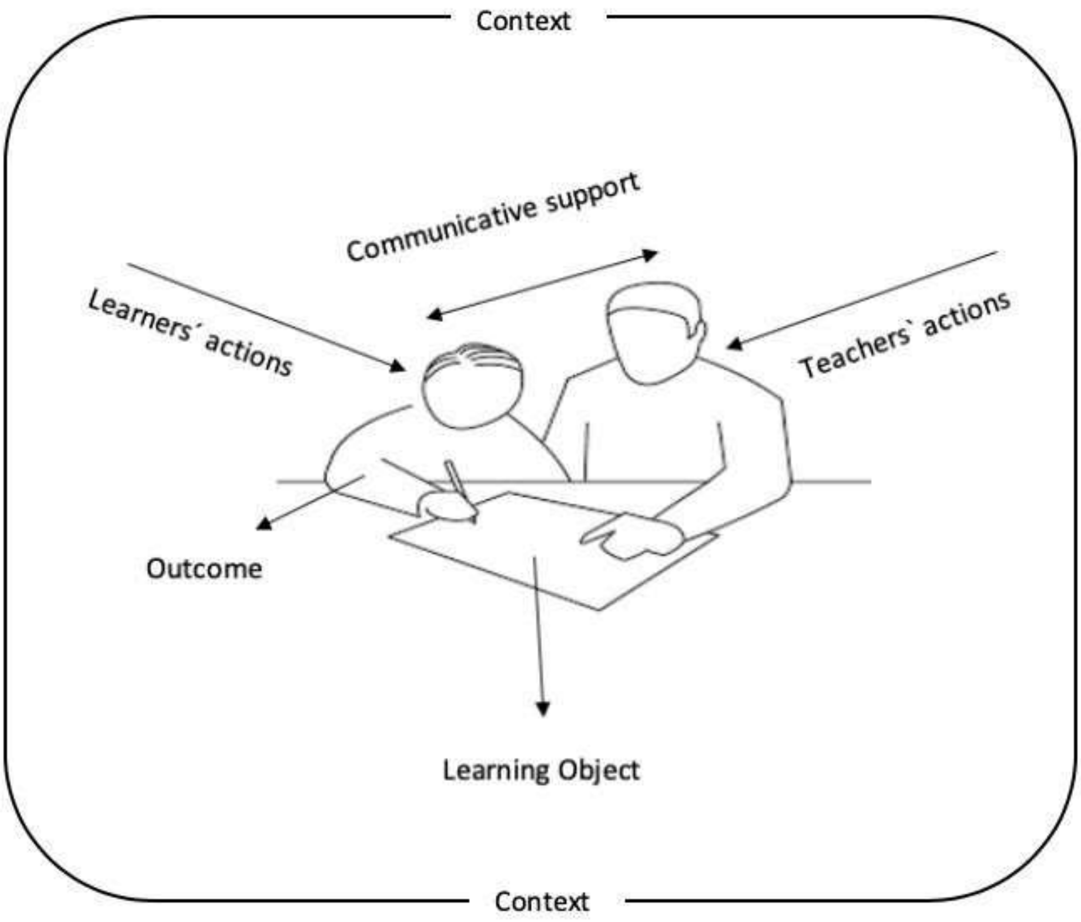
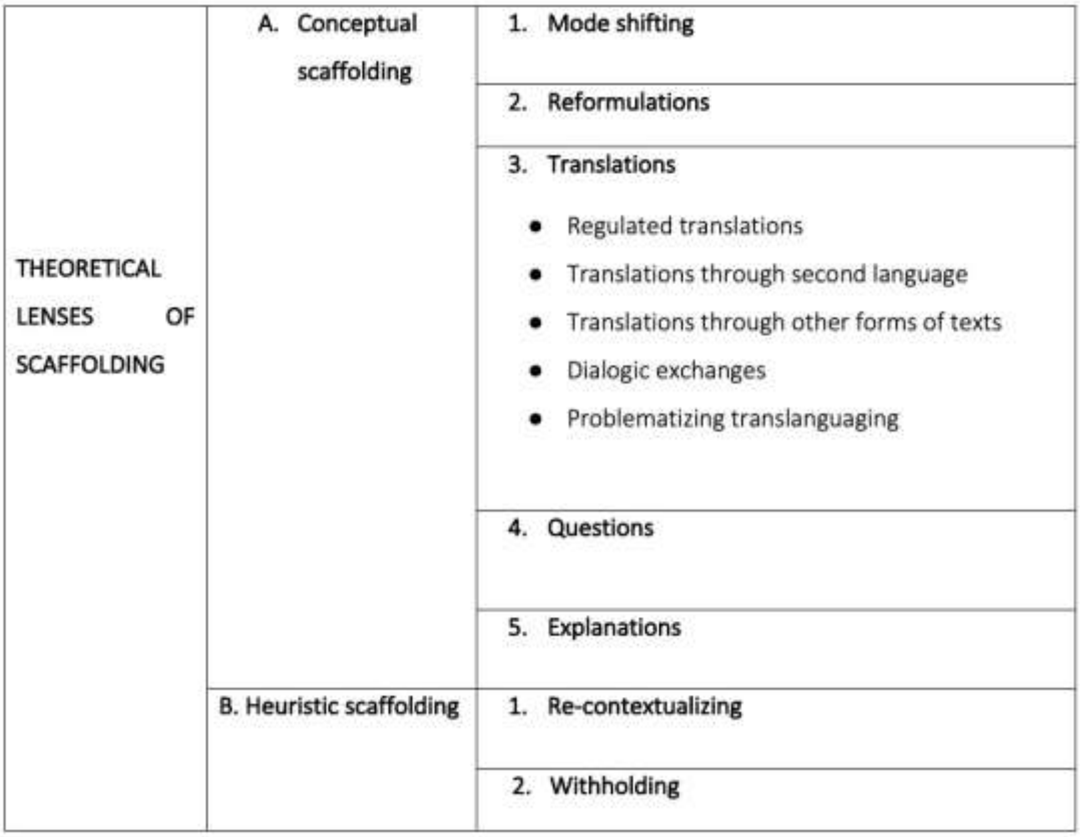


Figure 2: This figure represents the six-dimensions of scaffolding in study-guidance sessions.

These dimensions are used to study scaffolding in study-guidance sessions, where studyguidance teachers and newly-arrived pupils interact. In order to further analyse studyguidance sessions in Science using multilingual texts, theoretical lenses are presented in Table 1. The first theoretical lens, mode shifting is subsequently described in order to illustrate an example of using these theoretical lenses as analytical tools for this study.



THEORETICAL LENSES OF SCAFFOLDING	A. Conceptual scaffolding	1. Mode shifting
		2. Reformulations
		3. Translations • Regulated translations • Translations through second language • Translations through other forms of texts • Dialogic exchanges • Problematizing translanguaging
		4. Questions
		5. Explanations
	B. Heuristic scaffolding	1. Re-contextualizing
		2. Withholding

Table1: The table shows theoretical lenses of scaffolding.

Mode shifting

Study-guidance teachers use mode shifting between scientific language and everyday language during study-guidance sessions, which provide scaffolding for the newlyarrived pupils by enabling them to make connections between these discourses. Gibbons (2003) has shown that scaffolding actions take place through mode shifting between everyday and scientific language when teachers recast contributions of pupils. This is accepted as a bridge between the current abilities of the pupils and the demands of school curriculum.

The bridging might be interpreted as a scaffolding action in order to move pupils through the zone of proximal development by giving access to the description of a concept using both scientific terms and everyday language. This gives pupils access to scientific vocabulary by making the meaning of these terms transparent (Gibbons, 2003).

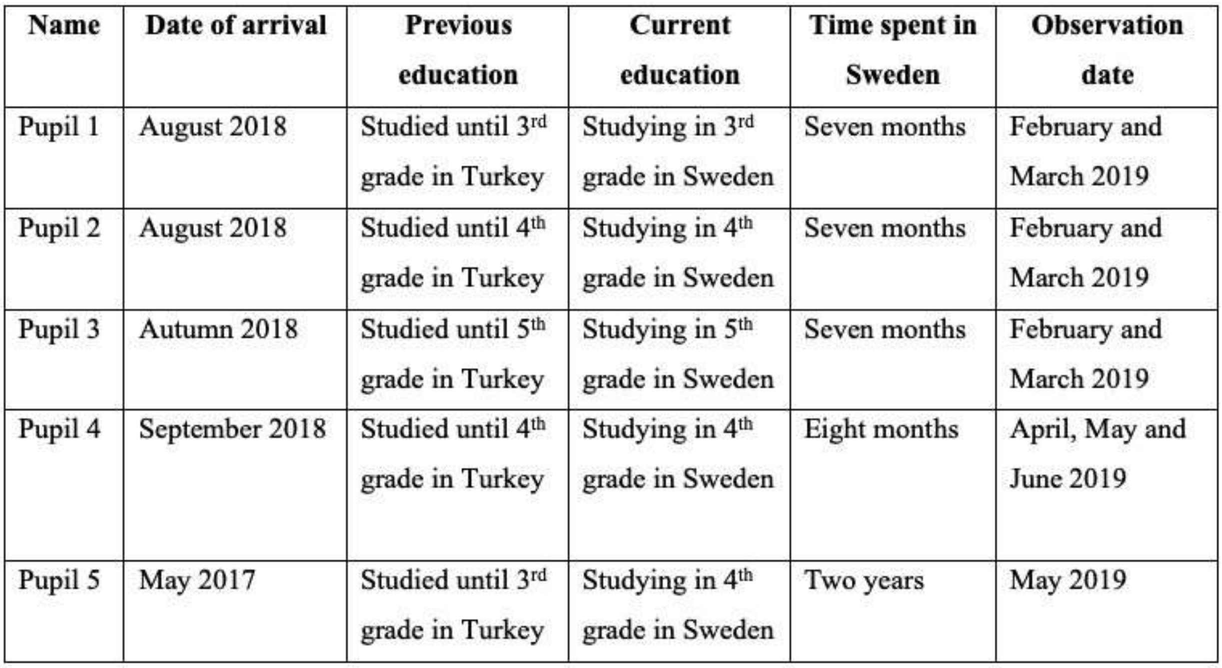
Methodology

This research project uses flexible research design, which can change and evolve during the research process (Robson & McCartan, 2016). Initial and tentative research questions were set at the beginning but they developed whilst the research was being conducted. Moreover, research design components such as data collection tools and sampling arose and expanded during the data collection process.

The data was collected mainly through the observation of five newly-arrived Turkish pupils and three study-guidance teachers during study-guidance sessions in four Swedish public schools in two eastern Swedish cities. It is considered to be fruitful to observe the meaning-making processes of newly-arrived pupils and how they make meanings, instead of asking them to explain it, as they are unlikely to possess full insight into their own meaning-making behaviours (Cohen, Manion & Morrison, 2000). Six study-guidance sessions were filmed in order to observe the interactions between the pupils and the studyguidance teachers.

Robson et al. (2016) stress that observation of behaviour is an effective research strategy in order to gain insights about individual development, however interviews open a window to see what lies behind these individual behaviours. Accordingly, complementary interviews were conducted with five newly-arrived Turkish pupils and three study-guidance teachers. Most of the questions were about the topics being studied, in order to garner more information about pupil´s meaning-making during the observation.

The sample consists of Turkish native-speaker pupils, who arrived to Sweden less than four years ago and who also receive study-guidance assistance. Accordingly, purposive sampling was adopted as a suitable sampling strategy, where the researcher built up a sample according to the specific research purposes (Robson et al., 2016).

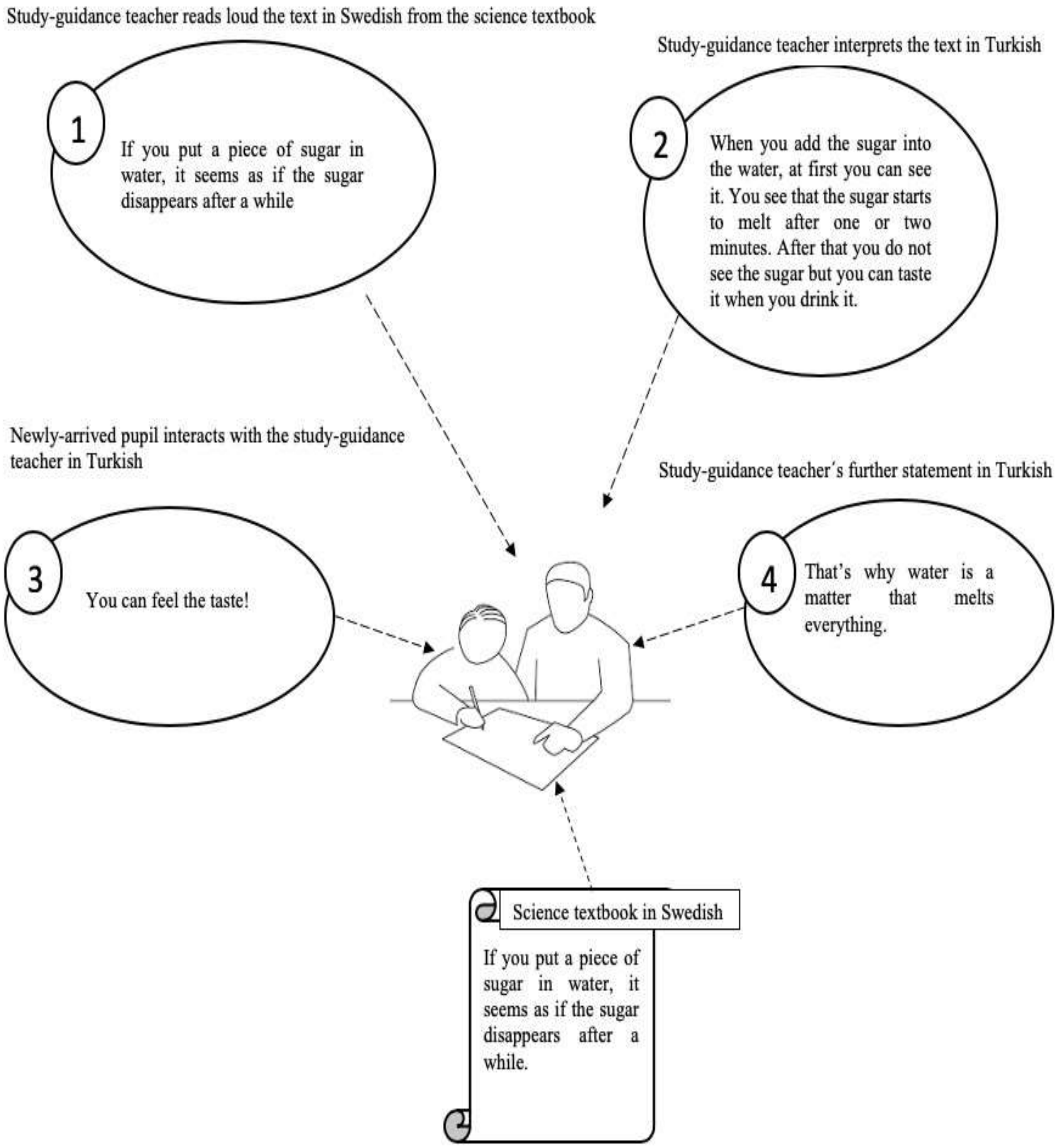


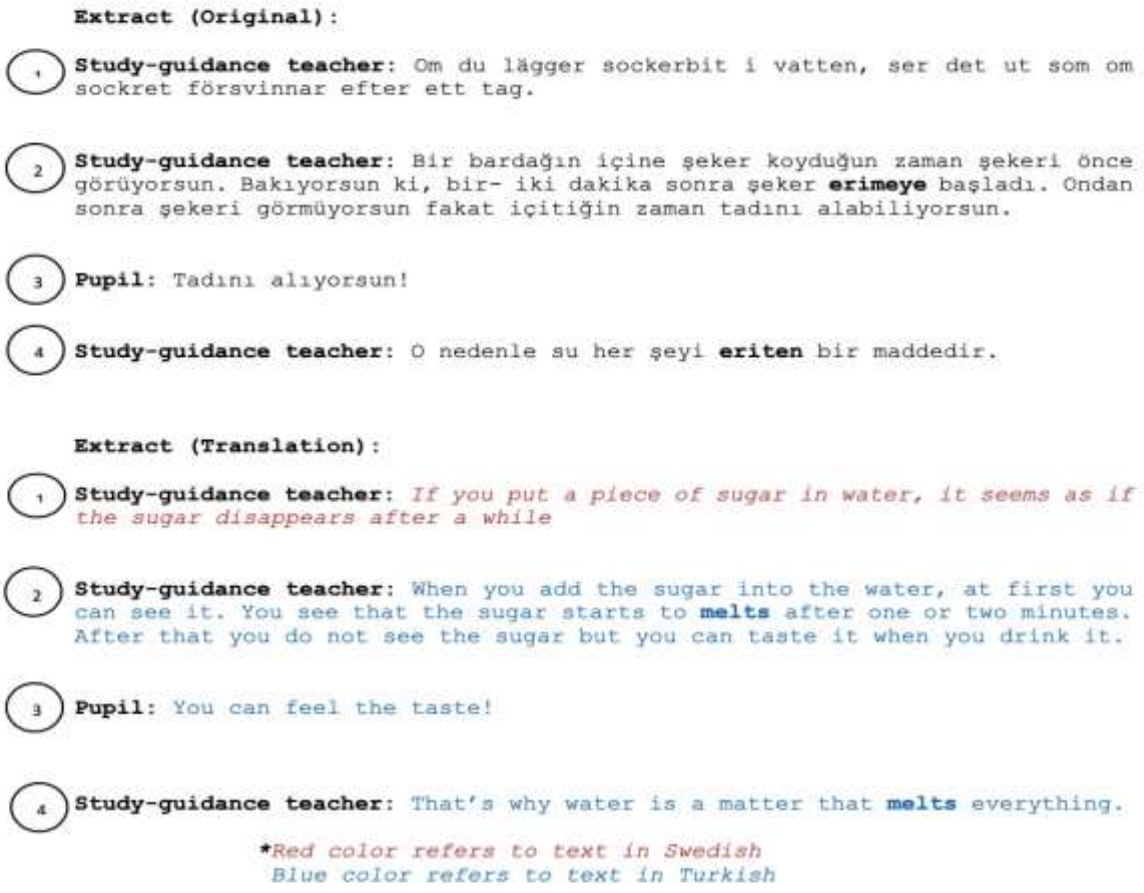
Name	Date of arrival	Previous education	Current education	Time spent in Sweden	Observation date
Pupil 1	August 2018	Studied until 3rd grade in Turkey	Studying in 3rd grade in Sweden	Seven months	February and March 2019
Pupil 2	August 2018	Studied until 4th grade in Turkey	Studying in 4th grade in Sweden	Seven months	February and March 2019
Pupil 3	Autumn 2018	Studied until 5th grade in Turkey	Studying in 5th grade in Sweden	Seven months	February and March 2019
Pupil 4	September 2018	Studied until 4th grade in Turkey	Studying in 4th grade in Sweden	Eight months	April, May and June 2019
Pupil 5	May 2017	Studied until 3rd grade in Turkey	Studying in 4th grade in Sweden	Two years	May 2019

Table 2: The table shows information about newly-arrived Turkish pupils.

Content analysis is used to describe the content of communication between the newlyarrived pupils and their teachers. The texts created in the dialogues and also written texts such as Science textbooks, worksheets or teacher's notes on the whiteboard were analysed by interpreting the meaning of the texts (Krippendorff, 2019). Besides, the analytical framework of the six dimensions of scaffolding linked with theoretical lenses is used to generate a pilot analysis. 20% of current data has been pre-analysed and more data is due to be collected in Autumn 2020 and analysed directly.

An example of a dialogue is provided below in order to demonstrate the challenges experienced during a scaffolded interaction between a study-guidance teacher and a newly-arrived pupil.


Study-guidance teacher reads loud the text in Swedish from the science textbook
1
If you put a piece of sugar in water, it seems as if the sugar disappears after a while
Study-guidance teacher interprets the text in Turkish
2
When you add the sugar into the water, at first you can see it. You see that the sugar starts to melt after one or two minutes. After that you do not see the sugar but you can taste it when you drink it.
Newly-arrived pupil interacts with the study-guidance teacher in Turkish
3
You can feel the taste!
Study-guidance teacher´s further statement in Turkish
4
That's why water is a matter that melts everything.
Science textbook in Swedish
If you put a piece of sugar in water, it seems as if the sugar disappears after a while.



Extract (Original):

① **Study-guidance teacher:** Om du lägger sockerbit i vatten, ser det ut som om sockret försvinnar efter ett tag.

② **Study-guidance teacher:** Bir bardağın içine şeker koyduğun zaman şekeri önce görüyorsun. Bakıyorsun ki, bir- iki dakika sonra şeker **erimeye** başladı. Ondan sonra şekeri görmüyorsun fakat içitiğin zaman tadını alabiliyorsun.

③ **Pupil:** Tadını alıyorsun!

④ **Study-guidance teacher:** O nedenle su her şeyi **eriten** bir maddedir.

Extract (Translation):

① **Study-guidance teacher:** *If you put a piece of sugar in water, it seems as if the sugar disappears after a while*

② **Study-guidance teacher:** When you add the sugar into the water, at first you can see it. You see that the sugar starts to **melts** after one or two minutes. After that you do not see the sugar but you can taste it when you drink it.

③ **Pupil:** You can feel the taste!

④ **Study-guidance teacher:** That's why water is a matter that **melts** everything.

**Red color refers to text in Swedish*
Blue color refers to text in Turkish

The learning object was defined as conceptual development in the context of studyguidance sessions in Science. Line-2 shows that the action of the teacher was to interpret the sentence (line-1), including mode shifting between the term "disappear" and "melt". Sugar does not *melt* in the water but it *dissolves*, thus the statement of the teacher was not scientifically accurate. In Turkish vernacular, it is very common to say that sugar melts in the water, which may lead to misconception. Subsequently, the action of the pupil was to repeat after the teacher. In line-3, the utterance of the pupil "you can feel the taste" was defined as an outcome, which gave an indication of the meaning-making processes of the pupil. Furthermore, the statement of the teacher (line-4) was not scientifically accurate since there are some substances, such as oil, that do not dissolve in water. In this example, the mode shifting action of the teacher could have scaffolded to promote the meaningmaking by the pupils of the term "dissolve". However, interpretation of scientific terms using the first-language is not always smooth, as it is dependent on the study-guidance teacher´s competence in using scientific language.

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Educational design to support the collaboration between physics researchers and high school teachers to foster scientific competences related to contemporary quantum physics

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Abstract

This research project aims to generate the conditions for the development of the scientific competences related to the understanding of contemporary physics core ideas at secondary school level. The attention is focused on the superposition principle and quantum entanglement as the key concepts of the second quantum revolution and its technological applications. In order to achieve this goal different types of activities to strengthen the collaboration between high school teachers and physics researchers have been planned. The intended outcome is to have data that could help teachers and researchers to create innovative physics curricula usable in regular secondary school educational activities.

Project outline

The latest EU recommendations on key competences for lifelong learning are focused on the implementation of competence-oriented education that could be facilitated "reinforcing collaboration between education, training and learning settings at all levels, and in different fields, to improve the continuity of learner competence development and the development of innovative learning approaches" (European Commision, 2018).

This collaboration is strategic in order to develop the scientific competences related to the key concepts of contemporary physics, such as the superposition principle and entanglement. Those topics are almost ignored by high schools (HS) physics curricula or are addressed for their philosophical aspects (Stadermann et al, 2019). Since these ideas are the core of the second quantum revolution (Baily and Finkelstein, 2015), it is urgent to make them accessible to HS students promoting and supporting the creation of innovative curricula (as suggested in the education pillar of the EU Quantum Flagship project https://qt.eu/) that could include technological applications like quantum computers and quantum cryptography. These educational activities could foster scientific literacy both by increasing the students' knowledge about specific scientific concepts and promoting scientific inquiry competences (Krijtenburg-Lewerissa, 2019).

In the framework of conceptual change, educational activities should guide HS students through the paradigmatic shift from classical to contemporary physics and the problems related to the quantum interpretation of reality based on the EPR paradox, entanglement and Bell Inequalities. These topics are also connected (Hadzidaki, 2008) to some aspects of nature of science like the existence of different scientific interpretations of reality and the relationship between experimental evidence and intuitive expectation (Baily and Finkelstein, 2015). In this context it is possible to make those ideas and reflections part of the young generation's "cultural capital", no matter the different students' future academic or professional careers.

Literature review

About teaching complex quantum concept like superposition and entanglement at secondary level, research into learning difficulties, effective teaching strategies and applicable assessment tools is needed (Krijtenburg-Lewerissa et al., 2017). Nevertheless researches in physics education (Dür and Heusler, 2014) (Michelini and Stefanel, 2008) suggest that is possible to introduce contemporary QP topics using a qubit approach (or Dirac approach) that emphasizes the fundamental role of the superposition principle in QP making it possible to introduce entanglement experiments of two-level systems (spin or quantum light polarization) using specific simulated experiments (Lopez-Incera and Dür, 2019) (Kohlne, 2015) (Kohlne and Deffebach, 2015). This approach is intended to reduce the problem of complex mathematical formalism (Pospiech, 1999) and could be easily adapted to HS maths curricula. The qubit concept could also be easily used to introduce QP technologies as quantum computers (Satanassi, 2019). We decide to perform real quantum experiments with HS students after proper training (Bondani, 2014) in order to explore the effectiveness of using experimental activities in quantum education and to support the reflection about the relationship between theoretical models and experimental results.

Research Questions

The aim of the research project is to generate the conditions for the development of scientific competences in HS that can support the paradigmatic shift needed for an appropriate understanding of the physical world as described by contemporary Quantum Physics (QP).

RQ1: How to define the framework of scientific competences related to an appropriate understanding of contemporary physics.

The process of understanding QP should include not only a transfer of basic concepts, but also a reflection on how a non-classical interpretation of reality is structured and which are the scientific competences that can be developed during such reflection. In the theoretical framework of the constructivist approach to learning it is important to understand how to facilitate the transition from a classical to quantum interpretation of physics phenomena and support the conceptual change process (McBride, 2010). Recent researches (Malgieri et al., 2017) in quantum education suggested the use of “framework theory” (Vosniadu et al., 2008) that defines conceptual change as a dynamic process that generates hybrid, synthetic explanatory frameworks that can evolve during instructional activities.

RQ2: What kind of educational activities could strengthen the relationship between HS teachers and QP researchers as members of the same educational ecosystem. Physics researchers and teachers are part of the same educational ecosystem (Royal Society, 2019) (Mueller and Toutain, 2015) and can contribute to its health not only by sharing knowledge about specific contents but also participating in designing educational activities. In order to create innovative physics curricula and feasible materials to be used in classroom activities, teachers and physics researchers should be engaged in curriculum design activity based on a clear definition of learning outcomes in terms of scientific competences. In this perspective a design-based educational approach is needed and the use of design frameworks (Wiggins and McTighe, 2005) could be part of the educational activities promoted in the context of the National Project Piano Lauree Scientifiche (PLS) (https://www.pianolaureescientifiche.it/). In particular the collaboration could promote experimental laboratory activities about complex quantum phenomena (superposition, entanglement and Bell’s inequalities) to help students understand the main characteristics of scientific research practices.

RQ3: What are the criteria that could be used for the effectiveness evaluation of educational activities related to contemporary quantum physics?
In the instructional design process, assessment plays a key role not only in shaping the tools to measure the efficacy of teaching/learning sequences but also in strengthening the coherence between instructional activities and intended learning outcomes (Biggs, 2011). Physics researchers and HS teachers can collaborate to make complex quantum topics accessible to HS students and to foster scientific competences only if they are able to codesign teaching and learning activities with an outcomes-based approach. The definition of specific criteria to evaluate and measure the effectiveness of educational activities for HS physics courses can improve the quality of the collaboration between researchers and teachers. The process of assessing the conceptual change could be provided using the knowledge integration theory (Liu et al., 2011) and its KI-rubrics that can scale how students link ideas and structure concepts (Liu et al., 2011).

Research design, methodology and methods

In order to investigate the proposed research questions, the project is structured in four different phases that involve physics researchers, HS teachers and students (see fig 1). The data collected from different sources (questionnaires, reflection sheets, interviews and audio recordings) will be used in a qualitative analysis to investigate the educational possibilities that could be pursued to introduce the qubit approach in term of knowledge acquisition and scientific competences development.

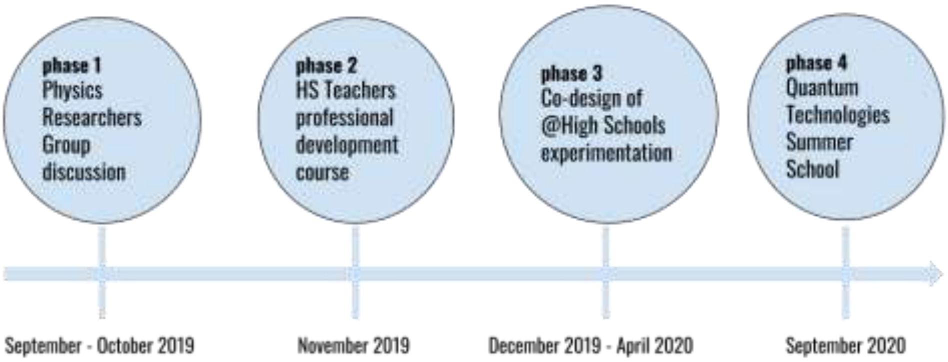

Figure 1. Project structure and related research questions

Nature and extent of the data collected so far

Phase 1. The group discussion with professional researchers and faculty members from three Physics Departments with experience in different fields of QP investigates which quantum topics experts consider to be important to teach at the secondary level. The reflections and arguments experts gave have been audio recorded and collected in short reports for a qualitative analysis focused on the balance between a rigorous transfer of specific QP topics (RQ1) and the development of scientific competences included in HS physics curricula (RQ2).

Phase 2. The professional development course engaged a group of 25 in-service physics teachers and is about the topics that should be included in a teaching - learning sequence aimed to move from the “old QP” (black body radiation, photoelectric effect, etc) to “contemporary QP” (superposition and entanglement). Every lesson has been video recorded and shared on a web portal to let other teachers have access to the course content. Teachers reflection was supported using online forms in which teachers could express their opinion about how complex quantum topics could be taught at HS (RQ2). A qualitative analysis of the form responses helped to identify the criteria teachers use to evaluate the feasibility and efficacy of the teaching sequence presented. (RQ1, RQ3)

Phase 3. A group of 4 physics teachers will participate in a co-design teaching activities with physics researchers using an outcome-based approach (Wiggins and McTighe, 2005). The intended products of these meetings are a collection of lesson plans, materials and assessment tools to run classroom and laboratory activities and rubrics to monitor student's learning process and scientific competences development (RQ3). We'll also collect teachers' opinion and written reflections to monitor the process of teaching activities design (RQ1, RQ2).

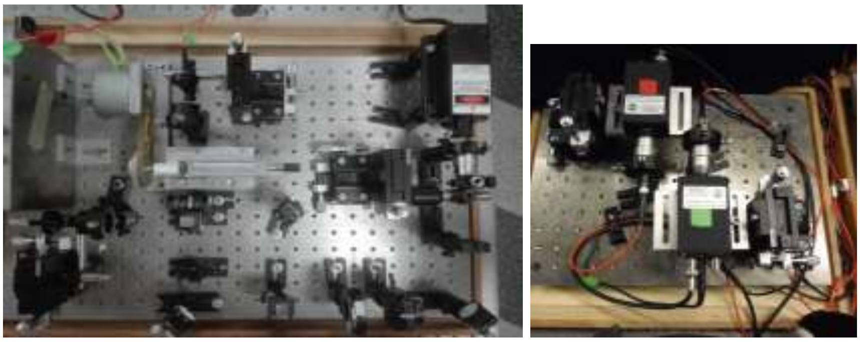

Figure 2. Mach-Zehnder interferometer experimental setup

Phase 4. Using hands-on experimental activities (Figure 2) and games, the Quantum Technologies Summer School will help HS students and teachers understanding how contemporary QP and quantum algorithms forged quantum technologies. One session will be about the use of IBM Qskit (https://qiskit.org/) to create quantum algorithms. We will collect data using questionnaires and formative test to monitor laboratory activities learning outcomes and student's reflections about the application of scientific research methodology (RQ2, RQ3) related to the development of new technologies. The qualitative analysis of data could help to understand to what extent these activities really support students' understanding of QP complex concepts and the process of organizing arguments about the interpretations of the results of quantum experiments.

Preliminary findings

The data collected so far helped the refinement of the designed activity and supported the reflection on RQ1 and RQ2. The group discussion with Physics researchers (Phase 1) defined superposition principle, entanglement and quantum measurements as the "core quantum concept that can lead to a proper understanding of contemporary QP". Teachers participated actively in Phase 2 but seemed resolutely attached to the idea that teaching QP is not feasible at HS due to students' poor mathematical preparation and the lack of teaching time available, confirming a vision of teaching as "marching through textbook" (Wiggins and McTighe, 2005) . The definition (Phase 1 and 2) of a phenomenological and non-axiomatic approach to the core concepts of QP reduces and simplifies the mathematical formalism (i.e matrices and complex numbers) using an algebraic based language valued in HS physics courses. Lesson materials and lecture notes produced can be used in the next phases. Before starting the activities with students, we send a questionnaire to 9 different High Schools in Lombardy to identify students' prior knowledge about QP and collected 106 responses. We intended to investigate how familiar the students are with some basic QP concepts that they could have already heard in previous science courses, schoolbooks and in the media (Figure 3).

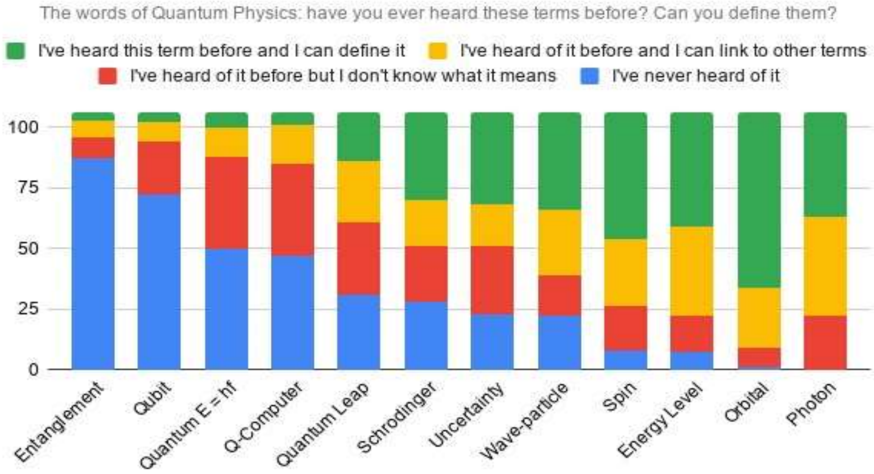

Figure 3. "The Words of Quantum Physics" questionnaire

We also asked students to "define" the concepts they know and create connections among them (Figure 4) using word-boxes to collect "linked concepts". The number of connections and the definitions provided confirm the idea that students struggle to built coherent connections between "Old QP" and "contemporary QP" and suggests how introducing the core concepts (Phase 1) in the educational activities (Phase 3 and 4) can help students understanding of how Old QP concepts changed to form a new vision of the physical world.

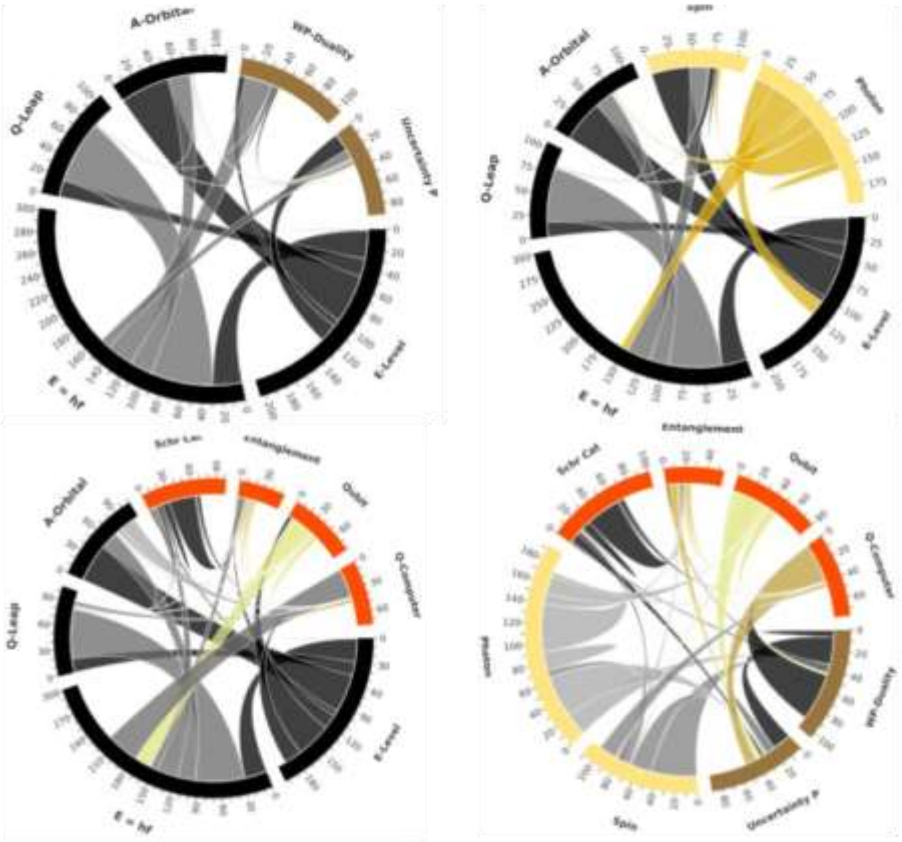

Figure 4.: Connections between quantum concepts before class experimentation

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Development of an empirically grounded learning performances framework for primary students’ modeling competency of water

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Abstract

A growing emphasis on students’ engagement in scientific practices is at the forefront of national and international reform efforts, which includes a focus on scientific modeling. (GDSU, 2013; NGSS, 2013). Understanding how models act as visual mediums and tools can support students’ sense making about system interaction by explicitly linking components, mechanisms, and sequences within complex natural phenomena, (e.g. the water cycle) which are covered across multiple grades, including primary. Within primary science classrooms, students should be afforded opportunities to learn about the nature and purpose of models, modeling, and real-world phenomena. To better support and develop primary students’ modeling competency, this study focuses on developing and refining a learning performances framework about modeling water. This framework investigates students’ knowledge across modeling practices, epistemic considerations, and water content. The dissertation also aims at developing and using a series of performance tasks and an interview protocol to empirically ground the framework.

Focus of the study

A growing emphasis on students’ engagement in scientific practices is at the forefront of national and international reform efforts (GDSU, 2013; NGSS lead states, 2013). This shift highlights scientific modeling as an authentic practice that students of all ages can and should be leveraging to reason about natural phenomena (NRC, 2012).
Understanding how models act as both visual mediums and tools can support students’ sense-making about system interaction by explicitly linking components, mechanisms, and sequences within complex natural phenomena (e.g. the water cycle), which are covered across multiple grades, including primary. To become competent in modeling, primary science classrooms should afford students opportunities to generate, explain, compare and evaluate models (Gilbert, 2004) and be engaged with the more epistemological features of modeling (Berland et al, 2016; Schwarz et al., 2009). My dissertation project – embedded in an ongoing international collaboration – aims to describe and investigate/assess the theoretical and empirical dimensions of primary students‘ modeling competency about the water cycle (as an exemplary disciplinary concept) with the help of a learning performances framework.

Review of relevant literature

Scientific modeling is a scientific practice through which students can visualize natural phenomena in order to reason and develop scientific understanding about complex processes and systems (Gilbert, 2004). When students engage in scientific modeling, they create (for example) an abstracted and simplified external representation of a phenomenon, a process, or a system. As such, models help make explicit processes and elements, ones that are often difficult to observe in natural settings, so that these connections and relationships become observable and can be investigated. Because of this inherent nature of modeling, it is a powerful cognitive process that allows the modeler to (a) explicate their current mental model and (b) to develop their ideas and reasoning about the phenomenon or process under investigation. The practices of modeling (construction, use, evaluation, and revision) represent actions students can take with models (Schwarz et al. 2009; NGSS lead states, 2013). These modeling practices include how students create and use scientific models to represent and explain phenomena, interpret experiences with phenomena, and critique and revise their models over time as they build understanding. The epistemic ideas of modeling tend to focus more generally on what a model is and how/why it can be used in science (Tasquier, Levrini & Dillon, 2016; Berland et. al, 2016). Modeling competence (Upmeier zu Belzen, Krüger & van Driel 2019) encompasses all of the above aspects, however, as such a complex, latent construct, it cannot be observed directly, needing manifestation during performance(s) (Shavelson, 2013). Therefore, performance-oriented (cognitive) tasks must are needed to allow researchers to make inferences from observable performances to students‘ (modeling) competence. Learning performances (Kracjik, McNeill & Reiser, 2007), integrating conceptual (i.e. content) and epistemic knowledge with scientific practices (i.e. scientific modeling), provide an important tool and construct through which to design such experiences for students.

One content area that would benefit from the development of a learning performances framework for modeling competency is water and Earth systems, due to its capacity to engage multiple disciplinary domains and prominence within primary science standards (GDSU, 2013; NGSS lead states, 2013). The water cycle is a foundational topic highlighted throughout the K-12 science curriculum (GDSU, 2013; NGSS lead states, 2013), including the primary grades. Specifically, early learners' understanding of the nature of water, how it cycles and changes state, and its relationship to human activities, are all necessary to help them make sense of everyday experiences. To develop conceptual understanding of hydrologic systems, primary students should engage in theory-driven scientific practices focused on the articulation, negotiation, and revision of model-based explanations (Forbes, Zangori & Schwarz, 2015; Windschitl, Thompson, & Braaten, 2008).

However, primary students often struggle to understand ideas around water (Forbes et al., 2015), holding alternative conceptions and/or lacking fundamental knowledge about water systems (Gunckel, Covitt, & Anderson, 2012).

A growing body of empirical research (e.g., Forbes, Lange-Schubert, Böschl & Vo, 2019; Gogolin & Krüger, 2016; Tasquier et al. 2017) and science education policy documents (NGSS lead states, 2013; GDSU, 2013) illustrate competence-based views on models and modeling and approaches to supporting students' use of models to reason about scientific phenomena while elaborating their modeling skills and epistemological knowledge on models and modeling. While this growing body of evidence is encouraging, assessing students' use of models and model-based reasoning to learn scientific concepts is challenging and little work has been conducted to develop, implement, and validate assessments of scientific modeling – especially in primary science education.

Research objectives

To address this need and gap in the literature, this multi-phase study – as part of an ongoing international collaboration – aims to explore:

How can primary students' integrated conceptual, epistemic and practice-based dimensions of modeling competency be adequately described, investigated and potentially assessed?

To answer this research question involves engaging in the following steps:

1) developing and refining a learning performances framework for primary students' modeling competency about the water cycle (as an exemplary disciplinary concept) (= step 1).
2) developing and using a series of performance tasks and an interview protocol to empirically ground the framework. (= step 2)
3) developing a task-based assessment for primary students' usage of models to understand the water cycle (= step 3)

Having completed the theoretical development of such a framework (step 1; see *Previous Work (Step 1)*) at this point, the current focus of the dissertation – and therefore of this synopsis – is step 2.

Previous work (step 1)

The conceptual framework that guides the development of the learning performances framework (see Tab. 1; Forbes et al. 2019) pulls from multiple perspectives about modeling focused across three dimensions (a) hydrological phenomena as the specific science *content* in which modeling will be situated, (b) *modeling practices* which represent engagement and application of scientific modeling with the content (c) and *epistemic considerations* of modeling which characterize students' knowledge construction about models more generally in relation to science. Combining these three dimensions resulted in the following conceptual and analytical frame, with its 21 theoretical learning performances, allowing to begin exploring primary students‘ modeling competencies about water.

Table 1 *Learning Performance Framework for Students' Modeling Competency*

		Modeling Practices		
		Construct/Revise	Use	Evaluate
Epistemic Considerations	**Nature of Models (A model is…)**			
	Evidence-based	Learner constructs or revises a model that incorporates evidence about a phenomena	Learner uses a model to incorporate new evidence about a phenomena	Learner evaluates a model based on the evidence provided about the phenomena
	Appropriately detailed/ complex	Learner constructs or revises a model that is appropriately detailed/complex to represent a phenomena	Learner uses a model that is appropriately detailed/complex to describe a phenomena	Learner evaluates the appropriateness of the complexity of a model pertaining to a phenomena
	Generalizable	Learner constructs or revises a model that is generalizable to/from a phenomena	Learner uses a model to make a generalization about a specific phenomena	Learner evaluates the generalizability of a model of a phenomena
	Purpose of Models (A model is for…)			
	Predict/ hypothesize	Learner constructs or revises a model that aids in making predictions or hypothesizing about a phenomena	Learner uses a model to predict and hypothesize about a phenomena	Learner evaluates a models ability to predict and hypothesize about a phenomena
	Explain (whole/ part)	Learner constructs or revises a model that aids in explaining some or all of a phenomena	Learner uses a model to explain some or all of a phenomena	Learner evaluates a models explanation of a phenomena
	Organize	Learner constructs or revises a model to organize their ideas about a phenomena	Learner uses a model to organize their ideas about a phenomena	Learner evaluates a models organization of a phenomena
	Generate	Learner constructs or revises a model to generate new information/ideas about a phenomena	Learner uses a model to generate new information/ideas about a phenomena	Learner evaluates a model to generate new information/ideas about a phenomena

Design and Methods

Context & Participants: Part of this multi-phase project is to empirically ground the theoretical learning performances framework (= step 2). Step 2 focuses specifically on the use of cognitive interviews around modeling tasks grounded in this framework and used to

investigate primary students' ideas within a German school setting. Situated within one 3rd-grade classroom and one 4th-grade classroom in a single German school near Leipzig, this study interviewed voluntary, individual students, ages 7-10, to explore if and how students could use models and modeling practices to engage in reasoning and thinking about the water cycle. These students were purposefully chosen (Patton, 2001) due to all of them having been taught about water (and water-related phenomena) at the point the interviews were conducted. (Focus) Group interviews might follow in another iteration of the study.
Development, Data Collection, & Analysis: To collect data for this exploratory, qualitative project, Evidence-Centered Design (e.g. Mislevy, Steinberg & Almond, 2003) was used to inform and guide the development of modeling tasks for students. EvidenceCentered Design as the methodological approach of choice, allows to align modeling characteristics from each dimension/cell of the theoretical framework with opportunities to elicit students' ideas and provide space to reflect on evidence thus gathered. One main aim being to identify, administer, and refine tasks to capture useable products for examination. Example tasks that were developed include having students select and describe the appropriateness of three different water cycle models, using a terrarium as an analogy to the larger water cycle, reflecting on different pieces of evidence and their appropriateness for inclusion in a water cycle model, and revision of a model using participants' mental models. Each task was also paired with questions asking students to reflect on their ideas, actions, and choices.
Data collection occurred in two phases so far, a pilot phase and an implementation phase. During the pilot phase of this project researchers iteratively developed a semi-structured (for reasons of standardization, e.g. in case of multiple interviewers) cognitive interview protocol (Patton, 2001) that included a task-based assessment which was piloted among students ages 6-10 (*n*=8) with the intent to capture a range of student ideas. Analysis from this pilot went towards refining the cognitive interview protocol and performance tasks. The refined version was given to experts in the field of science and modeling, then honed again before being implemented in the current cycle of interviews in 3rd/4th-grade classrooms. These student interviews (*n*=24) varied in length from six to thirty-four minutes and were audio recorded and transcribed and coded qualitatively in MAXQDA. A subset of these interviews was coded by two raters using a priori codes derived from the learning performances framework. Interrater agreement was eighty-five percent before discussion and one hundred percent after negotiation.

Preliminary findings

Results from student interviews and task-based assessments indicate that while primary students were able to engage in many areas of the learning performances framework not all were represented so far. An example occurred when primary students in the study struggled with evaluating the water cycle model for prediction. Even though students were asked directly to evaluate the predictive nature of a model (e.g. '*What do you think this model could tell us about the real water cycle, what could it predict*?'), each students' responses were vague, even when prompted for more detail.

While it is important to acknowledge these limitations, there were also parts of the framework students did engage in easily, such as evaluating the complexity of a model. When looking at complexity some students judged a water cycle model by the number of labels that were shown: "*This one is best because it has much more information …it has like very very* [sic] *many labels*" (Louis*). Other students looked at the more abstract pieces: "*I can tell there's arrows going up and down. I can tell it's rainy, it goes down on the river, and then it gets sucked back into the clouds and then goes again in the rain, like that.*" (Luka*). Luka thought a model was appropriately complex because he could trace the movement of water through the system. From varyingly complex responses likes these, the current main aim – besides to empirically ground the theoretical framework (= step 2) – is to discern different levels of students' engagement, for while both students are evaluating how complex a model is, Luka is displaying a potentially higher level of model competency by discussing abstract elements such as arrows.

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Navigating Open-Ended Spaces: Writing, Representing, and Speaking in a FifthGrade Science and Engineering Unit

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Abstract

This case study explores connections between the disciplinary practices of science and engineering and the development of disciplinary literacy practices in the context of a project-based unit in a single Grade 5 classroom. The goal of the work is to explore whether such a unit may provide a fertile context for students, particularly students with identities that have not historically been privileged in school settings in the United States, to be supported to successfully communicate their thinking in modes that are novel to elementary instruction.

Keywords: project-based learning, disciplinary literacy, engineering

Focus of Study

For my dissertation, I am examining the enactment of a Grade 5 interdisciplinary project-based unit for the purpose of exploring connections between the disciplinary practices of science and engineering and the development of disciplinary literacy practices. My advisor and I developed the Polynesian Wayfinding Unit, an eight-week investigation into oceanic navigation using only clues in the environment, as a component of the *Multiple Literacies in Project-based Learning* (ML-PBL) project[1], a design-based endeavor to create a science and engineering curriculum for the upper elementary grades aligned with the *Next Generation Science Standards* (NGSS, NGSS Lead States, 2013) in the United States.

Although project-based learning (PBL) has a long research tradition, the field could benefit from more observations of classroom-level lesson enactments integrating science, engineering, and literacy, particularly at the elementary level. Regarding the engineering components specifically, as engineering is a new subject at the elementary level in the USA, researchers and curriculum developers have many questions about what engineering design looks like with young children (Marshall & Berland, 2012).

The goal of my dissertation is to provide support for the emergent findings of my pilot study conducted during the 2018-19 school year, that an integrated science and engineering unit

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may provide a fertile context for students, particularly students with identities that have not historically been privileged in school settings in the United States, to be supported to successfully communicate their thinking in modes that are novel to elementary instruction. As conceptions about the particular shape and nature of effective supports for literacy in science and engineering at the elementary level are still developing, the question guiding my dissertation study is: *What features of a projectbased curriculum influence the writing, representing, and speaking of minoritized elementary students engaged in science and engineering?* **Literature Review**

Current reforms in elementary schools in the USA, represented primarily by the push for both the *Common Core State Standards in English Language Arts and Mathematics* (CCSS, National Governors Association, 2010) and the NGSS, represent the most recent attempt at providing a more rigorous education for the nation’s youth (Pea & Collins, 2008). One similarity between these two initiatives is to foster the sorts of higher-order thinking skills that are required for students to be college and career ready. Rather than memorizing or identifying facts, students are asked to think, speak, write, and engage in tasks that require deep comprehension, synthesis, and analysis. One approach for providing meaningful contexts for such tasks is project-based learning.

Project-based learning conceives of the educational experience as a coherent one, and stands in contrast to the way that disconnected content has often been presented as “science” to elementary-aged children (Davis & Krajcik, 2005). To craft coherent experiences, the PBL approach to curriculum design requires thoughtful planning, aligning standards from multiple subject areas, and selecting a “big idea” or organizing theme that is both meaningful and broad enough to support inquiry over the course of a number of weeks (Condliffe et al., 2017).

The *Multiple Literacies in Project-based Learning* project, for which I have served as a research assistant since the beginning of my doctoral studies and which provides the context for my dissertation work, is grounded in the design principles of project-based learning suggested by Krajcik & Czerniak (2014), including: using a *driving question*, encouraging students to *figure out phenomena*, providing *student choice*, and working towards the creation of a *final artifact*. As an effort to operationalize the reforms outlined in the NGSS, these features represent our team’s attempts to facilitate a shift in science education from merely *doing things* towards *doing things for a purpose* (Krajcik & Czerniak, 2014).

Too often, science and engineering are deemphasized in elementary education in favor of literacy instruction (Blank, 2013). One way to rectify this imbalance is the notion of *disciplinary literacy*, a conception of literacy that emphasizes the ways of reading writing, thinking, and reasoning particular to specific fields (Moje, 2008; Pearson, Moje, & Greenleaf, 2010). While this approach to literacy is one avenue for teaching science and engineering practices concurrently with literacy instruction, it remains to be seen how those disciplinary practices look with younger learners (Shanahan & Shanahan, 2014).

Similarly, the literature base regarding engineering education at the elementary level is still developing (Cunningham, 2018). As a result, there are still nearly as many questions as answers regarding the most effective ways to support students as they navigate this new terrain. From the available literature (Cunningham, 2018; Portsmore, 2009), it seems that young learners approach the engineering design process in ways different from more experienced designers. However, the field is still gathering evidence about effective contexts and supports for elementary students as they engage in developmentally appropriate design. Finally, and perhaps most importantly, those of us who are involved in science education reforms and designing engineering curricula for young children have an obligation to ensure that these new materials does not perpetuate inequities, particularly regarding race and gender, that have historically been prevalent in these fields (Cunningham, 2018). When coupled with the features of project-based learning, combining science and engineering design holds great promise for fostering structured approaches to ill-defined problems, for promoting a sense of agency towards making a difference in the world, and for providing an equitable context for *all* learners to participate.

Outline of Research Design, Methodology, and Methods Instructional Format

Like all of the ML-PBL units, the Wayfinding Unit is organized around a driving question (Krajcik & Czerniak, 2014); in this case, *How can we find our way in the world by using only the clues that are in our environment?* It includes 20 content lessons, four lessons per week for five weeks. Each lesson was taught for 1.5-2 hours, each containing literacy, science, engineering, and social studies components. The unit culminated with an additional 3 weeks dedicated to the creation of a pair of final projects: planning, building, and testing a models of a Polynesian-style double-hulled canoes, as well as creating short videos identifying an environmental problem and possible solutions.

Methods

The development of the ML-PBL curriculum follows a design-based research (DBR) approach (Brown, 1992). By wading into the messiness of authentic, everyday classroom life, DBR is intended to assist with the development of theory and the improvement of practice, while acknowledging the ever-shifting contextual variables that are an inherent feature of school life and, therefore, an inseparable feature of classroom interventions (Brown, 1992).

My dissertation study was conducted under the auspices of the larger ML-PBL project. After developing curricula for Grades 3 and 4 in previous years, we piloted the Grade 5 Wayfinding Unit during the 2018-19 school year. While selected pilot data will be referenced in my dissertation, the focus of my study is the revised, second iteration of the unit which was taught in October and November 2019. Within the context of the larger DBR curricular endeavor, I am using case study methods (Stake, 2006) and ethnographic tools for my data collection and analysis.

Context and Participants

The context for this study is a single Grade 5 classroom in a public elementary school in a semi-rural Midwestern town in the United States. The classroom teacher is a very experienced educator. Although she had great interest in PBL, her initial enactment of the Wayfinding Unit was her first experience with teaching a project-based curriculum. Her class had 19 males and 12 females for a total of 31 students. Eight students are African American, three are biracial, and twenty are white. Although classroom-level data is not available, schoolwide, 62% of students qualify for free or reduced-price lunch and approximately 21% of students have an identified disability. In order to highlight minoritized members of the classroom community as scientists and “doers of engineering” (Wright, Wendell, & Paugh, 2018, p. 285), I selected eleven minoritized students as focal participants when filming small group work or conducting interviews.

Data Sources

Data sources for this study include: (1) whole-class and small-group observations of every lesson, recorded using both video and fieldnotes; (2) classroom artifacts, including student notebooks; (3) interviews; and (4) assessment data. These data sources will provide me with direct evidence of student writing, representing, and speaking, as well as insight into student thinking. By comparing curricular materials, the teacher’s enactment, and student artifacts, I will be able to trace connections between features of the project-based curriculum and the influence, or not, on what, and in what ways, students communicate.

Status of Data Collection

I completed my classroom observations in November and I finished my postunit interviews with my focal participants and the teacher just last week. My immediate next step is to organize all of the data sources mentioned in the previous section. I will begin to process the data in January. By the time of the Summer School in June, I intend to be at least halfway through the writing of my dissertation. While my writing in the spring will focus on sections like describing the context of the study and writing the literature review, I see myself grappling with the findings by summertime.

Proposed Data Analysis

To answer my research question, I will use case study methods (Stake, 2006) and ethnographic tools. This choice is a response to, and an acknowledgement of, the situated nature of the learning context. My goal is to highlight these particular students, in this particular space and time, and what they think and do during this unit. By constructing this rich, contextualized descriptive case study, I hope to establish some level of transferability (Lincoln & Guba, 1985). That is, my intention is that other researchers and/or practitioners will be able to take the findings of this inquiry to be inspired to adapt these ideas for other students in different settings.

The case under investigation in this study will be this single classroom, engaged in the enactment of the ML-PBL Wayfinding Unit. I selected this bounded system (Barone, 2011), a classroom of fifth graders and their teacher, to provide evidence for my research question regarding the features of the curriculum that seem to be influencing the students' writing, representing, and speaking. By using multiple data sources over the course of an entire unit, I hope to be able to provide a substantive description of a complete arc of instruction.
The specific selection of the eleven focal students is guided by my explicit goal of highlighting students with identities that have not historically been privileged in school settings in the United States. I will engage in member checking with the classroom teacher, and, wherever possible, with the focal students, to make sure I am accurately representing their experiences. Considering the topic of the unit, and the intersectional identities of the students I intend to work with, this check on my positionality and bias is essential.

In particular, I will utilize a microethnographic analytic approach (Streeck & Mehus, 2004) to look at the interplay between context(s), interactions, and cognitive tools, in addition to mental activities, symbol use, and communication (p. 834). To do so, I will take a close look at students' writing, representations, and talk. I will analyze the data in three passes: (1) taking a close look at student artifacts, (2) examining student talk, in both whole-class and small-group interactions, and (3) combining the data sources to determine which features of the curriculum may have influenced the writing, representing, and speaking of the focal students.

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Examining dynamics that contribute to the initiation and sustenance of sensemaking in science

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Abstract (143 words)

Reform efforts suggest that science learning should be a sensemaking enterprise that positions students to construct and evaluate scientific explanations of phenomena. How students engage in sensemaking and what factors contribute to their sustained engagement are emerging questions. My study adds to research that explores these questions by examining and comparing the dynamics that contribute to engagement in scientific sensemaking in three groups of eighth grade biology students. Data include audio and video recordings of small group discussions, student artifacts, and stimulated-recall interviews. Preliminary findings identify that the ambiguous nature of the task as well as teacherstudent and student-student interactions alone cannot initiate and sustain sensemaking. Rather, the dynamic interactions of these factors intertwined with social and affective elements are needed to trigger and maintain sensemaking. This study contributes to the repertoire of factors typically considered in fostering productive disciplinary engagement in science.

Synopsis (2494 words) Study Focus

Current reforms present science education as a sensemaking enterprise that positions students to construct and evaluate scientific explanations as they work towards the goal of understanding scientific phenomena (NGSS Lead States, 2013). Scientific sensemaking is a process of inquiry in which learners grapple with inconsistencies in their attempts to develop coherent accounts of the natural world (Kapon, 2017; Odden & Russ, 2019b). While research highlights the importance of sensemaking in learning science (Odden & Russ, 2019a), there is limited empirical research that examines what initiates and sustains the process of sensemaking. In other words, how students engage in sensemaking and what sustains their engagement is an emerging field of research (Engle, Langer-Osuna, & McKinney de Royston, 2014; Odden & Russ, 2019a). This study contributes to this emerging research by examining the dynamics that initiate and sustain the sensemaking of eighth grade students working on a science task.

Literature Review

Sensemaking as a facet of inquiry involves the process of knowledge construction as students engage in the tacit evaluation and revision of their understanding of phenomena (Kapon, 2017). Often this process is in service of advancing the collective understanding of the phenomenon under investigation (van de Sande & Greeno, 2012). As students revise their understanding, they evaluate the soundness of their explanations using *intuitive knowledge* (everyday ways of knowing that they bring with them to the classroom), *mechanistic knowledge* (how the structural components such as different types of evidence influence the system), and *framing* (the work an individual understands to be important to productively engage in a task) (Kapon, 2017).

Student sensemaking is therefore a highly dynamic process influenced by how students interpret or frame a particular task (Hammer, Elby, Scherr, & Redish, 2005; Scherr & Hammer, 2009). This process of framing is shaped by a number of factors that include students' sense of how to construct knowledge (Hammer & Elby, 2002) and the social and emotional dynamics (e.g., joy and frustration during a task) that emerge in their disciplinary sensemaking efforts (Jaber & Hammer, 2016; van de Sande & Greeno, 2012). Social and emotional dynamics are often related to how groups collaboratively interact and construct knowledge together, an emphasis found in current science reforms that mirror authentic scientific practices (NGSS Lead States, 2013). During collaborative sensemaking, students work towards the alignment of multiple conceptual viewpoints in service of advancing a collective understanding of the phenomenon under investigation (van de Sande & Greeno, 2012). This process involves unique emotional challenges that have the potential to either sustain or inhibit student engagement. Do and Schallert (2004) found that positive affect was associated with heightened engagement (listening and responding to peers' ideas), while negative affect was associated with disengagement (tuning out) during group discussions.

Although research highlights the affordances of collective sensemaking, it must be recognized that collaborations can result in mixed outcomes (Barron, 2003). Groups that bring similar prior knowledge to a task can reach widely variable learning outcomes (Barron, 2003; Hogan, 2000). The success of collaborative sensemaking is associated with the nature of the social interactions in the groups, the different learning opportunities provided to the group members, and how those opportunities are taken up by the group (Conlin et al., 2007; Rogat et al., 2019). For a successful collaborative sensemaking endeavor, students need to attend to not only the conceptual contributions of their peers, but also to the social and emotional dynamics at play (Barron, 2003).

If we are to position students to construct scientific knowledge in the ways conceptualized in science education reforms, we need to further understand how students engage in scientific sensemaking as well as the factors that sustain or inhibit this engagement. By identifying factors that trigger sensemaking and by describing how that sensemaking undergoes periods of stability and instability, this work will be of interest to educators designing instruction to foster disciplinary engagement in science as well as researchers studying that engagement.

Research Questions

Research Question 1: How do the cognitive, epistemological, social and affective factors at the individual and collective (group) level initiate and sustain sensemaking in a small group?
Research Question 2: What are some commonalities and differences in group dynamics that either sustain or hinder collaborative sensemaking in the science classroom?

Research Design and Methodology

The study employs a naturalistic, qualitative approach to understand the dynamics of students' engagement in scientific sensemaking. I use a multimodal approach (Stivers & Sidnell, 2005) to examine, moment-to-moment, the ways in which students participate in a group sensemaking activity. Drawing on tools from video analysis (Derry et al., 2010) and discourse analysis (Gee, 2004), I work to capture both verbal (e.g., explicit discursive moves) and non-verbal (e.g., gestures, voice intonation and eye gaze) cognitive, epistemological, social and affective markers of sensemaking.
Context

The study occurred in an eighth grade biology classroom consisting of 25 students seated in smaller groups of 4 or 5 students. The data for the study was collected during the course of *one* lesson. The lesson, *Mechanisms of Evolution in Venezuelan Guppies* (Sampson & Schleigh, 2013), occurred across three days and positioned students to explore an existing data set and develop an evidence-based claim from those data in response to the guiding question: *What causes color variations in Venezualen Guppies?* The data set in the lesson was somewhat ambiguous, in that-there were multiple variables included with marked variation in the data for each. The lesson was structured using Claims-EvidenceReasoning instructional design, in which groups were asked to grapple with data and construct an argument as a result. The concepts targeted in the activity included natural selection, sexual selection, and the interplay between these mechanisms. The practices targeted included data analysis, explanation, and argumentation. Students spent much of their time during the lesson working in small groups to develop their argument with the goal of creating a poster to share with their peers towards the end of the lesson.

To address the first research question, I take a case study approach to examine the sensemaking of a small group. This group consisted of two boys (Desmond and Marshall) and two girls (Sandi and Jessie). These students were chosen for examination because they held different opinions about the data they were examining, generating a series of interesting discussions as they tried to resolve their differences and come to a consensus. The group's interactions were in contrast with the other students in the classroom who were observed to exhibit fewer differences in opinions. The analysis for the first research question will explore what kept this group's discussion sustained for approximately 50 minutes spanning two days, despite having little intervention from the teacher, Mr. Jerry.

The second research question takes a multiple case study approach comparing the focal group (group 1, described above) with two other groups. The second group (group 2) consists of five students (Ruth, Kendall, Asia, Chad and Joseph). The third group (group 3) consists of four students (Jasmine, Sari, Tan and Lee). Group 2 and group 3 varied in terms of the student interactions and nature of discourse and they came to a consensus fairly quickly and did not have sustained sensemaking. The analysis of the second research question will explore commonalities and differences in factors among the three groups that contributed to the initiation, sustenance, or termination of sensemaking during the course of the lesson.

Data Sources

The main data sources were video and audio recordings of the small group discussions, students' artifacts, and student stimulated-recall interviews. In the interviews, students were asked questions about their experiences in the lesson. The students were then shown selective video-clips of their group discussions and were asked questions about the chosen moment. The video-clips selected encompassed active moments of sensemaking and included rich social negotiations and affective displays. The video and audio recordings of classroom discussions as well as the interviews were transcribed. The student artifacts include each group's central argument (captured on a poster) as well as the individual laboratory reports.

Preliminary Findings

The analysis of the data is ongoing. Due to space constraints, I am presenting a brief overview of some of my preliminary findings addressing initiation and sustenance of sensemaking among student groups.

Initiation of Sensemaking: Role of Student Discourse

Following the initial round of sensemaking sparked by the ambiguous nature of the data presented in the task, the initiator of subsequent episodes varied among the three groups. One of the important initiators of subsequent rounds of sensemaking was the *need to resolve inconsistencies*-- in which at least one group member questioned or posed a statement of uncertainty. For instance, in group 1, this role was taken up by Sandi. As the group explored the data to explain what caused trends in the coloration of guppies, they settled on a number of explanations. Sandi, however, was dissatisfied with how the group was supporting each one of those explanations. She pressed the group to consider more deeply the reasoning behind their choices, by posing the following question,*"So, you think the haziness of the water affects that but do you think the, uh, especially the predatory fish also affect it? And you think that's affected by the upstream aspect?"* Sandi's questions problematized the group's initial bid towards consensus, highlighting a tacit *unresolved inconsistency* among the participants. Such moves served to initiate sensemaking as the group continued to grapple with the data to understand which of the data best explained the trends in coloration (i.e., turbidity and depth).

Similarly, in group 2, Chad and Joseph entertained several claims related to the data. For instance, Chad argued that the number of predators may be associated with the pool location *("Maybe there are less predators in the shallow and there's more in the deep.")*; his statement was problematized by Ruth (*"But pool 4 is deep and has no predators.").* Unlike group 1, however, instead of igniting sensemaking, such problematizing moves caused the students to abandon their claims.

Sustenance of Sensemaking: 'Ebbs' and 'Flows'

Analysis suggests that the persistence of sensemaking is marked by periods of stability and instability in which students oscillate between converging towards a consensus and experiencing subsequent moments of uncertainty. This happened in a number of ways including: when a group member vied to legitimize their claims against the competing claims of their peers, or when one student asked a question that destabilized the local understanding of the group.

Further, these oscillations were shaped by the nature of student's social roles in the group. Students assumed distinct roles such as making sure that everyone's ideas were heard or holding the group accountable to the norms of evidence-based reasoning. Sandi, for example, frequently positioned herself as valuing different ideas and pressing the group to "figure things out". She also made various moves to frame the activity as a collective sensemaking endeavor marked by her use of the "we" pronoun in her effort to invite the group to collectively analyze every explanation from multiple vantage points *(e.g., "So, do we think there are multiple factors?").*

Additionally, affective dynamics played a role in shaping these ebbs and flows. For example, wonderment was observed when students tentatively voiced their ideas using softer intonations or their eyes focused in the distance when they encountered a new unknown facet of the data. This wonderment was often followed by joy as evidenced in students' higher and more rapid speaking tones and their smiles as they worked to explain these new facets of the data. Frustration was evidenced (e.g., a head lowered to the desk) when inadequacies in student explanations were voiced and they were pushed into the ebb of uncertainty often resulting in nervousness when students were without a clear way forward in their sensemaking (e.g., giggling and humor to save face).

Further Analysis

My research is currently in an intermediary phase. Currently, I am analyzing the data with individual students as my unit of analysis and mapping the effect of cognitive, epistemological, social and affective factors in their sensemaking. A group level interactional analysis of these factors and how they initiate and sustain sensemaking will follow this. Furthermore, my analysis will also highlight implicit inequities in the group such as whose ideas get prioritised and who has access to the conversational floor and the role of these inequities in sustaining or hindering sensemaking.

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Sustainability in Out-of-School Science Education: Moving Towards the Future

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2483 words

1.0 Introduction

Humanity is facing global ‘wicked’ sustainability problems. Over recent decades, largescale environmental degradation has continued at a rapid pace. Rising global temperatures, plastic pollution, biodiversity loss, deforestation and other environmental issues require urgent action worldwide. In addition, large-scale social and economic issues such as poverty and inequality continue to affect millions of people across the world. In 2015, the UN formulated the seventeen Sustainable Development Goals (SDG’s). Together, these goals target different aspects of the global ‘wicked’ problems we face. There are significant gaps between scientific knowledge and public opinion (Clayton, 2017), attributed to scientists’ failure to communicate with learners using suitable language (Kadlec, 2009) but also widespread misconceptions within public and political spheres. New solutions are needed to prepare young citizens to address the serious issues we face, such as within out-of-school science institutions.

1.1 The Notion of Sustainability

As indicated by the UN, the global problems can be collectively thought of in terms of sustainability, a notion that has become ubiquitous in society (Stevenson, Ferreira, & Emery, 2016). Although sustainability has been interpreted in various ways (Purvis, Mao, & Robinson, 2018), the three dimensions of environment, society and economics all play major roles (Lele, 1991). Kates, (2011, p19449) refers to sustainability as “the ability to meet the needs of the present and future generations while substantially reducing poverty and conserving the planet’s life support systems”.

1.2 Sustainability Education

McFarlane & Ogazon, (2011, p86) state that “one of the major challenges to sustainability is education”. Over the past half century or more, this area of education has gone through a series of transformations, with less focus placed on the environment and more on sustainability (Stevenson, Ferreira, & Emery, 2016). These forms of education provide a platform to tackle how to best use and sustain resources on planet Earth (Coll, 2016).

1.3 Out of School Science Institutions

Out of school science institutions (museums, science centres, zoos and aquaria) are globally distributed, receive large numbers of visitors annually and are trusted by people from different political backgrounds, whilst also appealing to a diverse age-range (Clayton, 2017). There are many differences between these institutions, such as the techniques used to disseminate science, visitor demographics and how they are designed (Schwan, Grajal, & Lewalter, 2014).

2.0 Review of Relevant Literature

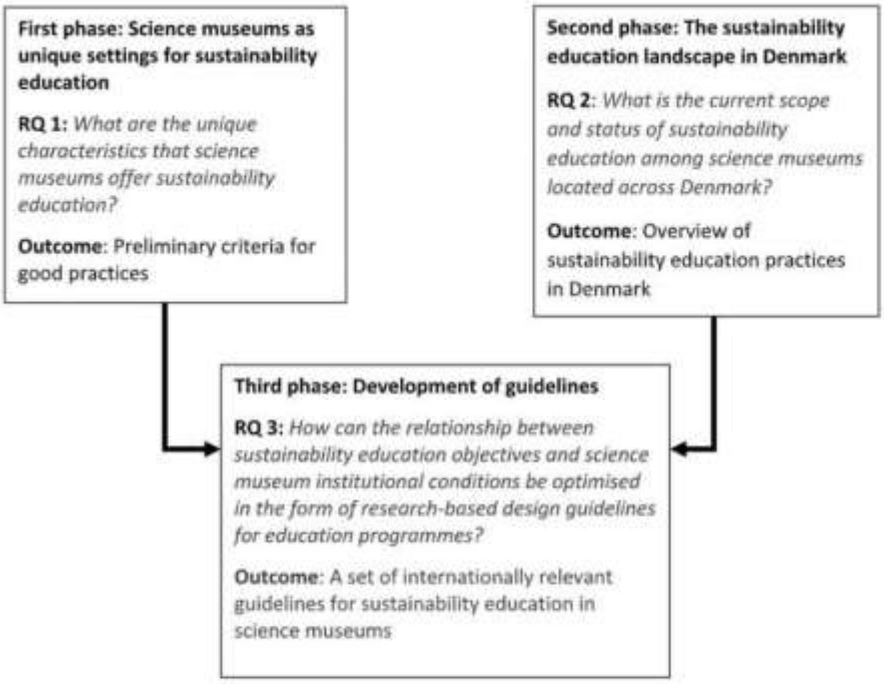
The notion of sustainability was developed in the intersection between science and society, rather than in the research domain. This led to a large increase in publications on sustainability within the research domain, known as sustainability science. Accordingly, a review of relevant literature must take into account the way sustainability is defined and discussed by societal actors, as well as the way it was subsequently developed into a coherent area of research among scientists. Finally, this section will include a brief review of relevant literature related to out-of-school science institutions. From the early 1970s, the term sustainability began to be frequently used in a wideranging, global context, and in 1972 the first global conference on environmental impacts associated with human activity took place in Stockholm (Purvis, Mao & Robinson, 2018). Sustainable development is a term often used as a synonym for sustainability. In 1987, the Brundtland Report defined sustainable development as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (Brundtland, 1987, p41). In 1992, politicians from around the world agreed to back the ideas behind sustainable development at the Earth Summit in Rio de Janeiro (Jordan & Voisey, 1998). This agreement was called ‘Agenda 21’.

Sustainability science is a young research field that has emerged over recent decades, with its roots found in the Brundtland Report (Komiyama & Takeuchi, 2006). Sustainability science investigates nature-society synergies, how these impact on global and local sustainability problems (Kates, 2011) and the solutions available (Spangenberg, 2011). It is viewed as being a critical part of moving towards a sustainable future (Spangenberg, 2011). To gain a better understanding of sustainability science, Bettencourt & Kaur, (2011) analysed publications produced between 1974 to 2010. A large increase in the numbers of publications occurred in the late 1980's and early 90's, linked to the release of the Brundtland Report in 1987 and Agenda 21 at Rio 1992. A study by Kajikawa et al., (2007) analysed the field of sustainability science, identifying 15 subdomains, with Agriculture, Energy, Fisheries and Tourism some examples of these.

Zoos and aquaria disseminate numerous topics with relevance for sustainability, but this dissemination is not explicitly labelled as such by these institutions (Heimlich, Searles & Atkins, 2014). A study by Heimlich, Searles & Atkins, (2014) analysed the education programmes of zoos and aquaria offered to visiting schools, finding the main topic associated with sustainability was biodiversity, with recycling second. There is a growing amount of literature on museums and science centres with regards to neutrality and activism on sustainability issues, such as Janes & Grattan, (2019).

3.0 Research Questions

This project will answer three research questions (Figure 1). First, it will clarify the unique characteristics (and conversely, the missed opportunities) that out-of-school science institutions offer sustainability education (RQ 1). Next, the current scope and status of sustainability education among out-of-school science institutions across Denmark will be researched (RQ 2). Finally, candidates will be chosen based on the preliminary criteria for good practices, for in-depth investigations. These will clarify how the relationship between sustainability education objectives and science museum institutional conditions can be optimised (RQ 3).



First phase: Science museums as unique settings for sustainability education

RQ 1: *What are the unique characteristics that science museums offer sustainability education?*

Outcome: Preliminary criteria for good practices

Second phase: The sustainability education landscape in Denmark

RQ 2: *What is the current scope and status of sustainability education among science museums located across Denmark?*

Outcome: Overview of sustainability education practices in Denmark

Third phase: Development of guidelines

RQ 3: *How can the relationship between sustainability education objectives and science museum institutional conditions be optimised in the form of research-based design guidelines for education programmes?*

Outcome: A set of internationally relevant guidelines for sustainability education in science museums

Figure 1 . The three research questions, with RQ 1 and RQ 2 feeding into RQ3. The general term of 'science museums' has now been replaced with 'out-of-school science institutions'.

4.0 Research design

As we have outlined in the preceding section, sustainability is a term meaning different things in different contexts. This implies that we cannot take any particular explication of sustainability as definitive, because that explication will always be adapted to the (scientific, societal, educational) context that it exists within. Instead, as science education researchers, we must construct our own point of reference that takes into account the various adaptations of sustainability. To this end, we employ the anthropological theory of didactics (ATD), which postulates that all objects of teaching, such as those found in zoo education programmes, have their origins in the objects of knowledge produced by scientific scholars (Chevallard & Bosch, 2014).

ATD is a research programme based on (among other things) the notion of didactic transposition, in which science in a research context is deconstructed and reconstructed into a suitable teaching form, then disseminated in an education environment (Chevallard & Bosch, 2014), such as an out-of-school science institution (Figure 2).

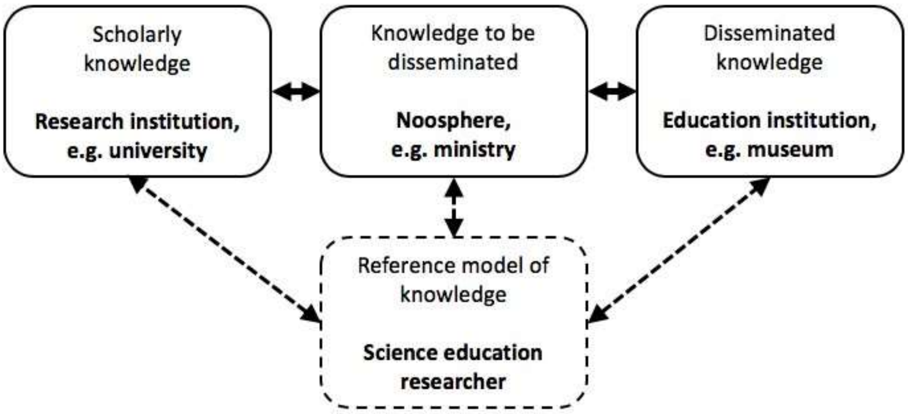


Figure 2 . The process of didactic transposition

Scientific research is labelled as scholarly knowledge, information predominantly formed at universities and other research based institutions (Chevallard & Bosch, 2014). Didactic transposition provides a method to analyse how an object of knowledge becomes an object of teaching. Issues can occur when knowledge is transformed in these sites (Bosch & Gascón, 2014) and the process of didactic transposition implies that the versions of knowledge found in educational institutions are not always the optimal ones. In this project, the scholarly knowledge is the research domain of sustainability science and the knowledge to be taught (within the *noosphere*) refers to the societal actors.

The research focus will be on Upper Primary and Lower Secondary school age-groups in Danish education (Grade 3-6). These age groups are still in the process of forming ideas, beliefs; additionally, the majority are very motivated to further their learning. This age group thus has a greater willingness to act on and engage in sustainability education, directly and indirectly influencing family and friends.

4.1 Methodology

4.1.1 First Phase

This phase has evolved to be more complex than previously anticipated. It has been deemed important to provide an elucidation of sustainability by investigating the scholarly knowledge within the emerging field of sustainability science, plus the societal actors within the noosphere. Finally, this phase will clarify the unique characteristics (and conversely, the missed opportunities) that out-of-school science institutions offer sustainability education, as well as the challenges and constraints (RQ 1). Preliminary data has been collected from practitioners of out-of-school science institutions and is used to form the reference model.

4.1.2 Second Phase

The second phase is split up into three parts (A-C), with its aim to generate a list of programmes and initiatives that are candidates for good practice. It will involve both quantitative and qualitative data collection and analysis. The preliminary criteria will be used to carry out a survey of sustainability education programmes offered by out-ofschool science institutions in Denmark to answer RQ 2.

Part A

The survey will involve an analysis of the institutions' websites and visitor marketing materials, for mentions regarding sustainability and its involvement of the day-to-day running of the site, including education programmes on offer for visiting schools groups.

Part B

Contact will be made to relevant people within the institutions, with a set of questions asked. Criteria for further inclusion will include target audience of programme, duration of programme, suitability of learning objectives, etc.

Part C

Visits will be carried out to the included institutions to gain insights about the programmes and activities selected in Part B. The visits will include interviews with the education team, observations of the sustainability education activities and exhibitions on offer, and interactions with visiting school-groups

4.1.3 Third Phase

Based on a comparison of the programmes selected and observed in the second phase of work, in the third phase, candidates will be selected for investigations of their educational efficacy. Indicators will be used to assess what constitutes good practice regarding sustainability education in out-of-school science institutions. Both quantitative and qualitative data will be collected to assess engagement as well as critical thinking and other factors. Based on these in-depth analyses, guidelines will be generated, which will constitute the answer to RQ 3.

5.0 Data Collected So Far

As part of the first phase, preliminary data has been collected from 15 educators based at 15 different Danish institutions (seven zoos, three aquaria, three museums, two science centres). The questions related to criteria for good practice when disseminating sustainability, as well as the five Sustainable Development Goals (SDGs) deemed most relevant/important for their institution. The five SDGs most commonly chosen by practitioners are shown in Table 1 below. These are used to delimit the notion of sustainability with relevance for the institutions in question.

Table 1. The five SDGs indicated by 15 educators in Danish out-of-school science institutions.

Sustainable Development Goal (SDG)	**Number of indications**
4 Quality Education	7/15
12 Responsible Consumption and Production	9/15
13 Climate Action	13/15
14 Life below Water	12/15
15 Life on Land	11/15

In Part A of the Second Phase, 39 educational programmes designed for visiting school groups between Grades 3-6 across 21 out-of-school science institutions located in Denmark have been chosen for further investigation.

6.0 Discussion of Analysis

Table 1 shows that the environmental goals of 12-15 are some of the most commonly chosen by practitioners. Goals 14 and 15 relate more specifically to biodiversity.

7.0 Preliminary Findings

- Sustainability was ‘founded’ within the *noosphere*, which led to a large increase of publications within sustainability science.
- The SDG’s are often deemed political and too complex for their inclusion in outof-school science institutions.

- The content on sustainability in the local school curriculum affects the programmes offered in out-of-school science institutions.
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Evolutionary bedtime stories: What can children (not) learn from storybooks that treat evolutionary issues?

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Abstract (150 words)

Even though evolutionary theory is used as the central concept in teaching biology to facilitate learning, students still face difficulties understanding evolutionary biology. Misconceptions emerge early by intuitive theory-building. The incorporation of biological concepts in early education might promote scientifically adequate thinking and decrease learning-hindering reasoning. Since books are the most commonly used media in families and contribute to cognitive development and formation of biological knowledge, we (1) analysed children's books concerning evolution, and (2) will conduct two intervention studies with children.

So far, we assessed ten out of 21 books in the categories organismal context, evolutionary principles, and misconceptions. Evolution is mainly presented in the context of animal evolution, while the principles variation, inheritance, and selection are hardly covered. Furthermore, teleological, transformationist, and anthropomorphic reasoning are present in most of the books. Based on the results, we consider variation to be promising to foster early scientific ideas about evolution.

Synopsis without abstract (2500 words)

Introduction

The theory of evolution explains how new hereditary traits are generated in populations by random genetic changes and how the process of natural selection shifts the frequency of these traits resulting in an adaptation of populations to their environments over generations (Tibell & Harms, 2017). Thus, evolutionary theory is the integrative framework of the life sciences and is used as the central concept in teaching biology. However, students of all ages still face difficulties in building an appropriate scientific understanding of evolutionary biology. Therefore, numerous empirical studies, focus on the enhancement of scientifically adequate knowledge (e.g., Lee et al., 2017), and misconceptions that counteract successful learning of evolution (e.g., Nehm & Reilly, 2007). Misconceptions mostly arise in childhood, when children attempt to explain the world based on everyday experiences (Kelemen, 2019). Following developmental psychology (e.g., Oerter & Montada, 2008), biological knowledge is developed domain-specifically. Each domain is governed by its own system of core theories with intuitive, internally coherent, and not necessarily scientifically correct principles and explanations. New knowledge is integrated and possibly transformed to fit into the existing system of core theories. These core theories cannot be reached directly by interventions, and a fundamental change requires longterm instruction. Thus, the incorporation of evolutionary biology in early education might promote scientifically adequate thinking structures (Kelemen et al. 2014). The project "EvoPrime: Evolution in Elementary to Primary Education" aims to identify ways to initiate evolutionary learning in early education in order to facilitate subsequent development of evolutionary knowledge in school.

Within families and day-care facilities, books are one of the most commonly used media (mpfs, 2015). They contribute to cognitive development in children (Bowman et al., 2000) and can promote early biological knowledge (Ganea et al., 2011). Moreover, they provide the opportunity to didactically prepare phenomena that are complex or hard to observe, such as evolution. Since 2015, we could realize an increasing trend in the publication of children's literature referring to evolution. However, Emmons et al. (2017) report that available books often do not meet scientific standards. While children's books may offer great potential for initiating evolutionary knowledge, conveyed erroneous or tendentious ideas can burden children's understanding of evolution and consolidate misconceptions.

Concepts that promote evolutionary knowledge include the biological principles variation, inheritance, and selection, as well as the abstract, non-biology-specific threshold concepts (randomness, probability, spatial and temporal scales) (Tibell & Harms, 2017). A lack of understanding variation is seen as a major obstacle to coherent evolutionary knowledge (Batzli et al., 2016), as it is the precondition for natural selection. So far, there is a desideratum of research on the extent to which children can acquire and apply knowledge about variation and whether an early understanding of variation favours the initiation of evolutionary knowledge (Bruckermann et al., 2019). An important threshold concept concerning variation is randomness. Due to natural selection, changes in populations often appear directed. Hence, an understanding of randomness (i.e., the lack of pattern or predictability of events) could lead to a reduction of teleological misconceptions regarding variation (Tibell & Harms, 2017).

Objectives

Within EvoPrime, the author's doctoral thesis addresses the question of how learning opportunities concerning evolution should be designed to promote first scientifically adequate ideas. The work will include one literature and two intervention studies that aim to answer the following questions:

S1) To what extent do available children's books provide content that can initiate or impede the acquisition of evolutionary knowledge, and which criteria can be deduced for the development of learning opportunities to initiate evolutionary knowledge?

S2) Does an intervention on variation increase the acceptance and understanding of within-species variation in children of kindergarten age and decrease misconceptions?

S3) Do children of primary school age show an increased acceptance of variation and less teleological misconceptions after an intervention on variation if it is supported by an integration of the threshold concept randomness?

Methods

Study 1. In a qualitative content analysis, children's books concerning the topic of evolution will be examined for implicit and explicit representations (Mayring & Fenzl, 2014) of evolutionary biological contents and misconceptions. Categories for the evolutionary content are deductively derived from Bohlin and colleagues (2017) and inductively differentiated and completed during piloting. Books were included in the analysis if they met the following criteria: (1) published and available for purchase, (2) the title or summary announces that the book deals with evolution, adaptation, or the emergence of life or biodiversity, (3) published in English or German, and (4) recommended beginning age ranges from two to six years. All books were classified into non-fiction books (NFB; i.e., explain aspects of scientific subjects) or storybooks (SB; i.e., tell the story of a protagonists’ experiences).

Study 2. The intervention study is designed quasi-experimental with a treatment and a baseline group (*N* = 60 each). Following Kelemen et al. (2014) and Emmons et al. (2017), the intervention will be implemented with a storybook on the variation of fictitious animal and plant populations with randomly occurring trait gain and loss. An intervention unit is scheduled for 30 minutes and carried out with groups of four children aged five to six years. A script will guide the realisation, and deviations will be documented. A pre- and post-survey examine a possible gain of acceptance and understanding on variation of the participants: The children are shown image sequences in a similar style to the used book. Guided by productive questions, they verbalize their ideas about variation, which are recorded and transcribed, while inaudible actions are documented. To measure learning outcomes, parts of the category system from study 1 are used and extended by the categories of Shtulman and Schulz (2008) on the type of justification. All materials are piloted with a small sample (*N* = 12).

We expect the treatment group to show higher acceptance and understanding of variation as well as fewer misconceptions in post-test than the control group.

Study 3. In the second intervention study, we use a 2x2 design with school children (first grade), who are divided into four groups (N = 60 each). Group 1 (RV) receives a learning unit for variation with a previous intervention on randomness. Group 2 (V) takes part in a learning unit on variation and group 3 (R) in an intervention unit on randomness. In addition, they receive an alternative unit without evolutionary reference, so that the interventions are comparable in terms of duration. The control group (C) receives two non-evolutionary treatments. The pre- and post-survey procedures of the study 2 are utilised. In addition, the acceptance and understanding of randomness in the biological context will be assessed. We expect the distribution of (1) increased acceptance and understanding to be like RV>V>R>C and (2) aroused misconceptions to be like RV<V<R<C.

Results

At the moment, we are conducting study 1. The complete analyses of study 1, as well as preparations of study 2, will be presented and discussed in greater detail at the ESERA Summer School.

Based on the search criteria of study 1, 21 books were found (eleven NFB and ten SB), all published between 2003 and 2019. So far, ten books (six NFB and four SB) were assessed concerning the categories of organismal context, principles, and misconceptions.

Organismal Context. Children's books mainly deal with animal evolution (n = 8). Human evolution is addressed in six books, five of which explain it in the light of animal evolution. Plant evolution is mentioned in only two books. In one NFB, evolution is symbolically explained using colourful balls.

Principles. The principles variation, inheritance, and selection are addressed in only half of the books, with a clear difference between NFB and SB: In 75% of the SB (n = 3), at least one of the principles is covered, whereas this is only the case in 33% of the NFB (n = 2). In total, the principle variation is mentioned in three books. In five books (three SB and two NFB), rather between-species variation is discussed than withinspecies variation (one SB and two NFB). Inheritance is only covered in one non-fiction book. The principle selection is addressed in all five books (three SB and two NFB).

Overall, only one NFB deals with all three principles.

Misconceptions. All analysed books contain at least one misconception (i.e., representations or explanations that promote misconceptions). In more than half of the books, teleological and transformationist ideas are expressed (n = 6). In contrast to NFB, SB contain a higher amount of anthropomorphisms (n = 3) and valuations of characteristics (n = 2). In four books (two NFB and two SB), evolution or natural selection are described as processes occurring in waves.

Discussion

Our results indicate that evolution is mainly presented in the context of animal evolution with low consideration of the evolutionary principles variation, inheritance, and selection. Since evolution is a universal principle, it is not bound to a specific phylum. However, the organismal context shows that animals and humans are preferred over plants. Neglecting botanical content is an often observed trend in evolution education (Hershey, 1996) that leads to problems of understanding (Pany, 2014). Hence, covering all organismal contexts may promote an overall understanding of evolutionary principles. However, other difficulties may arise since young children often do not perceive plants as living things (Yorek et al., 2009).

The principles (variation, inheritance, and selection) are critical for a meaningful understanding of the process of evolution (Tibell & Harms, 2017). Furthermore, studies show that preschool children are able to understand aspects of within-species variation (e.g., Emmons & Kelemen, 2015), inheritance (e.g., Raman, 2018), and selection (e.g., Emmons et al., 2017). Nevertheless, these principles are hardly touched in the books, which could be explained by the fact that the term evolution is seemingly equated with the earth's history. Six of the ten books present eras and some characteristic species, while the origin of species is often not mentioned (transformationist approach; see also Emmons et al., 2017) or explained by referring to functionality or purpose (teleological approach; see also Hammann & Asshoff, 2015).

Anthropomorphisms increasingly appear in the SB, probably to make the stories more illustrative or entertaining. This includes the ability to induce speciation or expression of traits by conscious decision-making. Differences between species (i.e., advantages of one species in order to survive in a particular habitat) are more often emphasized than within-species variation. Such representations are per se scientifically correct but can promote essentialist thinking by allocating one trait to all the individuals of a species. Moreover, children are more willing to accept within-species variation if the advantages of a trait are not mentioned previously (Emmons & Kelemen, 2015).

So far, the analysed children's books convey complex knowledge about evolution without explaining basic principles. They not only promote existing transformationist and anthropomorphic misconceptions but introduce less prominent teleological ideas as well as contexts that decrease children's acceptance of variation. Werther (2016) argues that evolutionary biology should be taught in primary schools immediately after the domain shift towards the autonomous biological domain. We also consider such a step to be meaningful by initiating evolutionary knowledge in order to promote early scientific ideas about the principles variation, inheritance, and selection. Particularly fostering the understanding of variation seems to be a promising first step since children reach a higher level of scientific understanding about adaptation when it comes to experienceable aspects (Werther, 2016), which is the case for the principle variation. Thus, we will apply the storybook-intervention to see to what extend children in kindergarten (study 2) and elementary school (study 3) are able to learn about variation in order to initiate evolutionary knowledge.

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Investigating the effects of instructional support to improve writing in context of scientific inquiry

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Introduction

In Germany, both national and international education monitoring highlight a connection between the language students speak at home and the acquisition of competences in science (Pöhlmann et al., 2013; Rauch et al., 2016). Students whose mother tongue is German achieve higher competence levels in science compared to students who do not speak German at home (Pöhlmann et al., 2013). This correlation is particularly relevant in the federal state of North-Rhine Westphalia, where many students with a migration background live and who do not speak German as their first language. Against the background of previous research in this context we know that language is a key factor for science learning and the development of scientific literacy (e.g. Härtig et al., 2015; Krajcik & Sutherland, 2010; Özcan, 2013). Therefore, there is a need to support students with poor (German) language related preconditions.

Theoretical Background

One aspect of scientific literacy which is especially difficult for students is writing scientific texts. Wellington & Osborne (2001) argue that "writing in science is not something which is peripheral to the learning of science […]" (p. 81) but essentially influences the development of scientific literacy and thus, of an understanding of the content of science itself. Also, Mammino (2010) points out that language mastering has a big impact on students' performance in science. Writing any kind of text requires lexical and grammatical knowledge, knowledge of text patterns, writing and content related knowledge (Bachmann & Becker-Mrotzek, 2017; Becker-Mrotzek & Böttcher, 2006; Sumfleth & Özcan, 2016). In order to support students in writing scientific texts, support strategies should be based on scientific thinking and working methods. Science teaching based on the concept of inquiry-based learning requires students to produce a high degree of subject-specific text, usually in form of experimental reports.

Schneider et al. (2012) point out that for the lower secondary level there are only few empirically supported findings regarding the effectiveness of supporting methods, both for reading and for writing texts, which include experimental reports. Moreover, there are almost no findings on the differential effects of instructional methods that consider the different social or linguistic backgrounds of the students.

However, the essential characteristics of scientific language in contrast to everyday language are well known. An important aspect is the use of scientific vocabulary. On the one hand, students are confronted with many unknown terms (e.g. titration, oxidation). On the other hand, they already know science related terms from everyday life (e.g. salt, fat) (Emden et al., 2015). Furthermore, there are proper names or compound terms (composites) that distinguish science language from everyday language (Emden et al., 2015; Rincke, 2010). In addition to the difficulties at the word level, there are also many typical sentence structures which pose a challenge for students (Beese & Roll, 2015; Leisen, 2010).
One possibility to support scientific literacy is language-sensitive teaching, in which ‘language is learned on and with the content’ [translated from German] (Leisen, 2010, p. 6). For the natural sciences, this means that language learning takes place within inquiry-based learning. Leisen (2010) proposes strategies for language-sensitive teaching that promote both text production and the acquisition of content knowledge. However, there are no findings with regard to the differential effect of these methods in dependence of relevant student preconditions.

Goals and research questions

The main objective of the project is the empirical investigation of the effectiveness of instructional methods that support writing in science against the background of relevant learner characteristics and preconditions. Although linguistic competences are firmly anchored in the curricula of chemistry teaching in Germany, there are so far only few findings on the impact of support strategies in this area, especially in connection with scientific ways of thinking and working.

Considering this theoretical background, the following research questions can be formulated:
RQ1: *“To what extent do writing support strategies affect the linguistic and content related quality of experimental reports in the context of inquiry-based learning?”*
RQ2: *“To what extent do these effects differ regarding the different linguistic backgrounds of students?”*

Methods and study design

The first milestone of the project is the development of instructional methods that aim to support students in writing scientific texts. Those methods will be implemented in the context of inquiry-based learning. Furtak et al. (2012) reported an overall mean effect size for inquiry-based learning of d = 0.90. A “positive trend favoring inquiry-based instructional practices” over traditional approaches has also been stated by Minner et al. (2010, p. 1) and other studies. Text production in inquiry-based contexts, i.e. the writing of experimental reports, is a standard situation in science and chemistry teaching (Conference of Ministers of Education [KMK], 2005). Different forms of presentation and appropriate formulations are expected in the report. The individual sections within the report itself differ from each other (Beese & Roll, 2015). The products of the writing process can, for example, be formulated research questions on scientific phenomena, hypotheses on possible explanations or detailed descriptions of the experimental project including implementation and observation. In the subsequent evaluation, a precise scientific explanation of the facts is also necessary. Within a quasi-experimental study in a pre-post design the effectiveness of different instructional methods derived from Leisen (2010) will be investigated. The following methods have been selected as characteristics of the independent variable:

I. Writing according to an **example text** (support at text level)
II. Writing with **sentence blocks** (support at sentence level)
III. Writing with the help of a **word list** (support at word level)

It is assumed that the effects of the instructional methods presented to promote writing differ depending on the (scientific) linguistic background of the students. On the one hand, it can be assumed that the strategy “writing according to an example text” is more likely to help learners with unfavorable linguistic preconditions. Writing with a word list, on the other hand, will presumably be beneficial for learners with more favorable preconditions. In general, the characteristics of experimental reports in science education have often been studied (e.g. Bayrak et al., 2015; Beese & Roll, 2015; Wellington & Osborne, 2001). However, in order to be able to develop appropriate support strategies it is necessary to have precise knowledge of the scientific language and requirements of a report, especially for the selected topic ‘properties of salts and salt solutions’. Just as in the main study, the students will be presented with two video items and write a report for the experiment shown.

For the analysis of the text products, content related and scientific language criteria for writing an adequate report have been derived from a literature review to create a coding manual. The criteria will be applied to 8th or 9th grade students’ experimental reports by at least two independent raters to check the reliability of the instrument. Also, the criteria will be augmented inductively as appropriate. Further, the reports are evaluated based on these criteria and the scientific language difficulties of the participating students are worked out.

On the basis of the results of this preliminary study, the support strategies for the main study can be prepared so that they are available in summer 2020.

The scientific language and content knowledge presented within the experimental report form the dependent variables which are addressed by the intervention. It is expected that the strategies will have an influence on both dependent variables, as the support strategies also provide support for content knowledge development. In addition to the three experimental groups (one for each instructional support), there will be a control group which does not get any support.

To provide a sample as diverse as possible, about 150 participants for each of the four conditions will be recruited out of different school types in North-Rhine Westphalia. A sample size of in total 600 students also enables to compare the impact of the instructional support measures. The main criterion for recruitment of any chemistry class is that the students already finished the topic ‘properties of salts and salt solutions’ which is mainly the case in the 8th or 9th grade depending on the school type. This is important due to the influence content knowledge has on the linguistic performance of the students. The participating students will be randomly assigned to one of the four conditions within every class to equally distribute students from different school types across the treatment groups of the intervention.

A content knowledge test at the pre- and post-measurement time is used to measure the students’ content knowledge in the particular content area (control variable). The test will be developed based on the test from Çelik and Walpuski (2018, in preparation). An open writing task representing different report sections is used at both measurement times to determine the scientific language and content related competences (dependent variables). The text products will be evaluated by the criteria received in the preliminary study. Furthermore, basic language competences and cognitive abilities are surveyed as control variables with the help of a general c-test and the cognitive abilities test according to Heller & Perleth (2000). For c-tests a good reliability ($r \approx .90$) has been reported in many studies (Coleman et al., 2002). For the cognitive abilities test an internal consistency between $r = 0.80$ and 0.90 has been reported. Thus, both instruments are well established.

The design of the intervention is described below. As an initial situation, the students are presented with a video on a tablet chemical phenomenon that introduces them to the topic of the respective lesson in a problem-oriented way. In this way, the formulation of questions and hypotheses can be specifically initiated. A second video will then be shown. This video shows the execution of an experiment which fits to a previously anticipated question incl. hypothesis and is suitable to verify or falsify the hypothesis. The videos are each provided with a task. The video and the task together form a video item (Engl et al., 2015), which creates a writing occasion. On the basis of the video items, the participants first formulate questions and appropriate hypotheses. After the second video item, the experiment execution and observation are then written down in order to evaluate the experiment in the report afterwards. To provide controlled conditions every participant will get an own tablet with video-items. By randomly assigning the students within every class to one of the four groups quasi-experimental conditions can be assured. The students also will be instructed and supervised by the conductor of the intervention to work on their task on their own. The whole process combining the two video items and writing tasks will take roughly 45 to 60 minutes.

The texts produced by the students during the intervention and the texts of the pre- and post-measurement are evaluated based on the criteria derived from the preliminary study. The texts produced are independently evaluated by at least two trained raters with regard to the linguistic and content-related characteristics mentioned earlier. The agreement of both ratings is determined by Cohens-Kappa κ after the first part of coding to check the reliability of the instrument.

The previous thoughts result in the following study design (Figure 1):

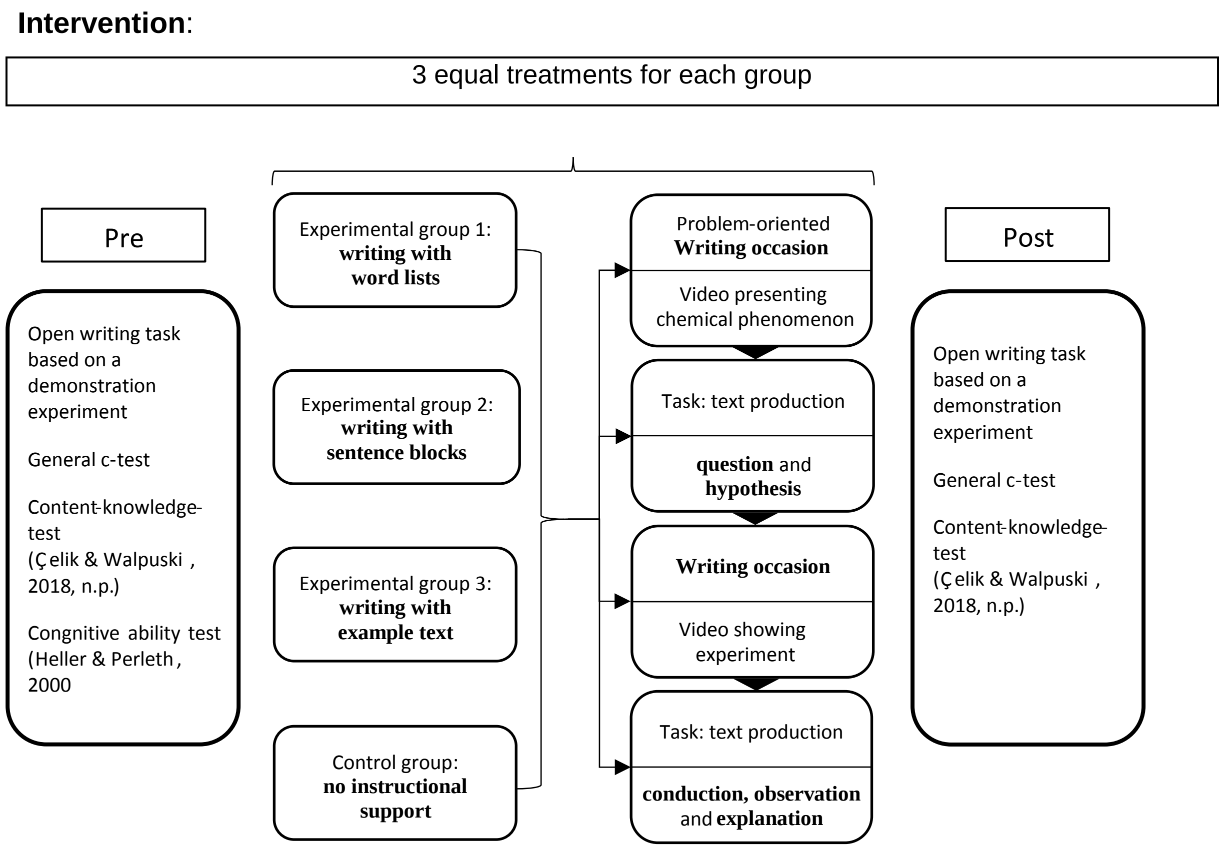

Figure 1: Study design and test instruments.

As mentioned before the topic of the intervention is ‘properties of salts and salt solutions’. This topic was chosen because in many cases it requires a change between the macroscopic and submicroscopic level (e.g. in solution processes). The distinction between the macroscopic level and the submicroscopic level is of great importance for the learner's understanding. However, Bucat & Mocerino (2009) reported that the two levels are often not clearly separated from each other, both in oral and written communication.

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Teaching plate tectonics through scientific practices: an instructional approach supporting students' exploratory talk

Julie Guttormsem

Introduction

This is a qualitative study focusing on lower secondary school students learning plate tectonics with the aim of developing a learning resource. In the new national science curriculum in Norway for general education, *Kunnskapsløftet 2020*, the theory of plate tectonics is emphasized in two attainment goals. However, research on teaching and learning about plate tectonics is scarce, and more research is needed on instructional approaches on the subject (Mills, 2016). Additional research presents students' misconceptions on important geological processes such as earthquakes, rock formation and volcanoes (Francek, 2013). In line with international trends, the Norwegian national curriculum has shifted from a focus on inquiry to scientific practices.

Therefore, this PhD-project builds on the aforementioned research as well as theoretical perspectives on science learning. The project is undertaken as Design-based Research in several cycles, where two out of three cycles have so far been carried out. Based on the data analysis from cycle 1, a 12 hours teaching design was developed together with teachers. The teaching design of cycle 2 has been tested with a class of 20 students (aged 13). The teaching activities aim to engage students in scientific practices across classroom and the local environment to learn about plate boundaries and consequential formation of major rock types.

Research questions

Based on theoretical perspectives, this study examines how scientific modelling of plate boundaries can influence and enhance student conceptual understanding and how exploratory talk may result through the modelling activities.

The specific research questions are:

a) *To what extent are lower secondary school students' discussions exploratory while modelling plate tectonic processes?*

b) *What conceptual understanding do secondary students express while constructing models of plate boundaries during group activities?*

c) *How can relevant scientific practices be incorporated in the teaching resources on plate tectonics?*

Theoretical perspectives

Scientific practices has since 2012 received increased attention in reform documents in science education in the US and Europe, and there is a trending shift from inquiry based science education (IBSE) to a more practice based science education (Crawford, 2014). IBSE was critiqued due to a poor common understanding of what inquiry actually entails (Osborne, 2014). In the Framework for K-12 Science Education, the main communicative activities of science presented were doing science, representing science, talking science, writing and reading science (NRC, 2012). Eight scientific practices were presented as representing ways of *doing* science. Crawford (2014) describe these eight practices of science as the following activities:

- *questioning and defining problems*
- *modelling*
- *carry out investigations*
- *analyse and interpret data*
- *use mathematics and computational thinking*
- *explaining and make solutions*
- *engage in argument from evidence*
- *obtaining, evaluating and communicate information*

From a sociocultural perspective, talking or interaction is a key element in how humans develop meaning and understanding of the world around them. The use of language is essential to learning and in knowledge in its own state. According to Vygotsky (1986) thoughts come into existence by words, in line with NRC (2012) who defines talking science as one of the main activities of learning science. Mercer and Howe (2012) use sociocultural theory in understanding the educational functions of classroom talk, and discuss the concept of exploratory talk in light of sociocultural theory. They present the following description of the term exploratory talk:

"… Exploratory Talk represents a joint, co-ordinated form of co-reasoning in language, with speakers sharing knowledge, challenging ideas, evaluating evidence and considering options in a reasoned and equitable way. They present their ideas as clearly and as explicitly as necessary for them to become shared and jointly analysed and evaluated. Possible explanations are compared and joint decisions reached."

Mercer and Howe (2012)

While designing a teaching and learning environment supporting the development and occurrence of exploratory talk, it is crucial to pay attention to both properties of teacherstudent talk and collaborative talk. The cultural form of teacher-student interaction has historically been authoritative, rather than dialogic (Mercer and Howe, 2012). Students' collaborative talk can be used as a tool for reasoning and as a means of scaffolding the development of reasoning and scientific understanding (Mercer, Dawes, Wegerif, & Sams, 2004). Concepts relevant to supporting student knowledge development by the means of a guiding role, are often referred to as “scaffolding”, “guided participation” or “dialogic teaching” (Mercer et al., 2004). A teacher or fellow students can represent this guiding role.

Methods, analysis and research design

This is a qualitative design based research study, with data collected from two schools in Southeast Norway. The students are from 8th grade (13 years old), attending lower secondary schools. So far, 3 teachers, 2 classes and 46 students have participated in the project, two of three cycles of the teaching design has been tested (see Table 1 for details). The data comprise video material recorded by action cameras during classes, video data and voice recordings from pre- and post-interviews with students, written or produced material developed by students (drawings, models etc.), and observations. By using action cameras, both verbal communication and activities become registered, however there are some ethical considerations influencing the data when children wear head cameras (Frøyland, Remmen, Mork, Ødegaard, & Christiansen, 2015). Considering the transferability of results, the selection of schools represented in this study is made on practical reasons; hence, the selection represents traditional public schools from rural areas. Teachers were interviewed after each lesson, in order to get additional feedback on their reflections and experiences towards the teaching design, and especially towards events when the teacher had to support students through dialogue.

Student groups wearing head cameras during the 8-12 hours teaching designs creates a large sum of data, hence a reduction of data is necessary. The data are organized in the software program Nvivo, and further categorized by coding the content to thematic groups based on the theoretical framework by Richards (2009). The thematic coding and sorting of events into categories involves minimal interpretation (Richards, 2009).

The research design of this study is based on the methodology of Design based research, described by Brown (Brown, 1992). Relevant and clarifying considerations to this framework, with a focus on design *for* learning, is presented by Goodyear and Dimitriadis (2013). The teaching design of the first cycle consisted of an online learning environment (the Vitenplatform, www.viten.no) produced by the Norwegian Center for Science Education, composed of multimodal presentations and activities where students were to observe, infer and discuss the different processes of plate tectonics, as well as multiple kinds of evidence supporting the theory. The development of the theory concerning its transition from the theory of continental drift, postulated by Wegener was also a component of the learning environment. Followed by the activity in the learning environment, the students worked together in preparing a poster presenting one of the three main types of plate boundaries. The teaching design of cycle one lasted approximately for 8 hours.

Table 1: Description of the two completed cycles, content for cycle three will be based on the analysis of cycle two.

	Cycle one	Cycle two	Cycle three
Student activities	Online learning resource: reading, observing, discussing, inferring in pairs on the history of plate tectonics, evidence supporting the theory and the processes related to the theory. Students work in groups producing a poster describing processes at one of the three plate boundaries (constructive, destructive, transform).	Student groups received a mission: to develop an exhibition describing the processes forming the local bedrock. Students collected rock samples, studied them and related the rock to the most plausible plate boundary responsible for producing the rocks. The groups developed a model of the plate boundary in the virtual space of Minecraft. Finally, students placed their exhibition at the schools' library and each group presented their findings.	Recommendations for the teaching design will be based on a discussion of the data from cycle two.

Teacher activities	Dividing students in groups, supporting students during their work in the Vitenplatform. Presenting the poster-assignment, supporting students during their posterpreparation	Dividing students in groups, presenting the exhibition-assignment, collectively going through the Viten-platform, supporting students during a rock sorting activity, guiding and assessing students through preparation for fieldwork, providing scaffolding to students while describing rocks and inferring rock type to plate boundary. Supporting students while making models in Minecraft and completing the assignment.	
Time spent	8 hours	12 hours	

Preliminary findings

Student post-interviews from the first cycle involving the online learning environment indicates that students' conceptions about the processes of plate tectonics in most cases are inconclusive, indicating a lack of internalization of concepts. This interpretation is supported by observations where students showed uncertainty while describing the formation processes of volcanoes and how tectonic plates move, the driving mechanisms of plate tectonics, Earth's layers and their link to tectonic plates. However, during post-interviews, most students could express one of the key arguments supporting the theory of plate tectonics, the argument saying that continents have been formerly linked together in a super continent (Pangaea). Many of the students could also relate volcanoes, mountains and trenches as products of plate tectonics.

Based on the low proportion of conceptual understanding developed during cycle one witnessed by the post-interviews, a shift from the general point of view to a more local perspective on plate tectonics was hypothesized to increase students' learning potential for cycle two. Hence, the teaching unit was re-designed to involve the schools' local geology. In the second teaching design, the main activity for student groups was to develop an exhibition including rock samples from the schools' local environment, followed by inferring the formation of the rocks to a particular plate boundary, and finally presenting the plate boundary through a 3D model in the software program Minecraft Education.

Considering the framework of scientific practices (NRC, 2012; Crawford, 2014), several practices were incorporated in cycle two of the teaching design, presented in the table below:

Scientific practice	**Description of procedure (cycle two)**
Carrying out investigations	To develop the exhibition requested, the students sampled rocks from the schools' neighborhood, in order to infer the rock type. They had to practice collecting rock samples and use maps to position their findings.
Analyse and interpret data	The students used their conceptual knowledge about the three main rock types (sedimentary, metamorphic and igneous) and their patterns, in order to identify the local rock type. They also had to interpret geological maps to identify faults (geological structures), also indicating type of plate boundary.
Engage in argument from evidence	In combination of interpretations of maps and sampled rocks, the students could infer and argue about the local rock formation process; hence deduce the historic plate boundary in the schools' neighborhood.
Modelling	Based on the interpretation of the local rock type and geological maps, students collaborated on developing a 3D model of the historic plate boundary in the software Minecraft Education.

Table 2: Scientific practices and details concerning their implementation, present in the teaching design of cycle two.

The pre-interviews of the second cycle shows that students were generally unaware of the effect plate tectonics has on shaping the exterior of the Earth, through processes such as plate collisions. Many students expressed misconceptions regarding the formation of volcanoes, exemplified by drawings of volcanoes with their magma chambers connected to the Earth's core. This observation is consistent with known misconceptions (Francek, 2013). Overall, the data implicate a trend that students' pre-instructional ideas are far from comprehending that the Earth's outer lithosphere consists of plates.

Analysing parts of the collected data from the second cycle, it seems likely that the combination of practices included in cycle two (Table 2) implicated a greater need for guiding and scaffolding through the different activities. In particular, the processes of analysing and interpreting data from geological maps and inferring the tectonic plate boundary seemed challenging for several of the student groups. Hence, a preliminary consideration is that there is a requirement to improve the scaffolding structures related to this particular practice.

The process of scaffolding could be optimized by involving students further through studentteacher or class-teacher dialogues, with a particular focus on teachers' questioning practices (Mercer & Howe, 2012). During the student groups' collaborative process of developing the model of a plate boundary, preliminary observations implicate that students are "interthinking" (Mercer & Howe, 2012), while working together in the virtual reality of Minecraft Education. According to Mercer and Howe (2012), the concept of interthinking involves students not only interacting, but also maintaining a shared conception of the task or problem through the collaboration. So far, a few episodes indicating students' exploratory talk in line with the description presented by Mercer and Howe (2012) has been identified. In the further analysis of the data, I will continue to analyse the student discussions and the characteristics of the student-teacher dialogue with respects to theoretical perspectives.

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Constructing a diagnostic instrument for wave optics

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Abstract:

Wave optics phenomena, such as interference, diffraction and polarisation of light are often very difficult concepts for students. The existing studies about students' difficulties with wave optics were mostly conducted on university level students. This study is focused on secondary school students from Croatia and Austria, who learn about wave optics in their regular physics courses. The main goal of this study is to develop a new diagnostic instrument for wave optics, **C**onceptual **T**est on **W**ave **O**ptics (CTWO), that could serve teachers and researchers in evaluating secondary school students' understanding of wave optics. The study will have a qualitative part where the nature of students' difficulties will be investigated via demonstration interviews, and a quantitative part where a set of ca. 60 items will be tested on large groups of students and Rasch analysed until a test of ca. 25 well-functioning items is obtained.

KEY WORDS: students' difficulties, wave optics, test construction, Rasch model

An outline of the study

This study is focused on the educational aspect of wave optics of secondary school students and it belongs in the fields of physics education research and physics didactics. The goal of this study is to construct a new diagnostic instrument in a form of multiplechoice test that could be used for assessing secondary school student's conceptual understanding of selected concepts of wave optics, either for teaching or research purposes. The statistical Rasch model will be used in evaluation of the new instrument construction. The new instrument will be research based.

Many problems concerning the students' understanding of basic concepts in wave optics (interference, diffraction, polarisation, etc.) were already identified through physics education research studies, but most of them were conducted on university students. This study will try to fill the existing gap in the research by focusing on the secondary school students. Secondary school (gymnasium) students from Croatia and Austria will take part in the validation of multiple-choice test. Probing the test in the two countries may contribute to the validity of the new instrument and its wider applicability.

In Croatia, students encounter the topic of wave optics for the first time in the fourth grade of secondary school (age 18-19). It is regulated by the Croatian physics curriculum what students will learn about (interference, diffraction and polarisation of light). Those topics from wave optics are covered in about six to seven weeks in two or three 45 – minutes periods per week. In Austria, students learn about wave optics a year earlier, in the eleventh grade (age 17-18). Teachers in Austria have the freedom to choose themselves what topics to cover. Wave optics is typically covered in four to six weeks in two or three 50 – minutes periods per week.

A review of relevant literature

The findings of longitudinal study conducted at the University of Washington, USA (Ambrose et al, 1999) showed students' lack of a coherent framework for optics. The identified student difficulties were grouped in three categories: misapplication of geometrical and physical optics (students often create hybrid models of optics), the lack of a qualitative understanding of the wave model, and problems with modern physics concepts.
First-year students from South Africa University of technology showed misunderstanding of the superposition principle (Coetzee and Imenda, 2012). They considered interference as 'reinforcement' effect resulting only in bigger waves and treated waves as objects.
One study in Turkey showed that Turkish first-year college students often create alternative models of light when trying to explain different phenomena. It was also showed that the rays are usually not recognised as just a geometrical representation of the light's path (Şengören, 2010).

220 French students (aged 19 – 23) took a questionnaire about situations where wave optics needed to be used, after lessons on wave optics (Maurines, 2010). It was shown that students preferred using the ray-model of incident light rather than Huygens – Fresnel principle. A lot of difficulties concerning a small aperture were found (i.e. edges of the small aperture refract the rays of the incident wave).

Some authors tried to explain why students have difficulties with wave optics phenomena. There was a suggestion that the source of the difficulties could be that in school teaching all concepts seem to be treated as isolated concepts (Colombo, Jaen and de Cudmani, 1995) and others suggested that difficulties could be due to the students' misreading of the drawings used in optics (Colin and Viennot, 2001).

72 second year secondary school students (age 16-17) from Bosnia and Herzegovina took part in the study that investigated the effect of the wave representation on secondary school students' understanding of wave optics (Mešić, 2016). For the study a 15 – items diagnostic instrument was developed (Basic Wave Optics Survey – BWOS), that covered double slit

interference, single-slit diffraction and diffraction on a diffraction grating. The test did not include the polarisation of light, but it included the multiple-slit interference. The results showed that the items where students were asked to predict changes in the observed patterns when the wavelength of incident light was changed were the most difficult for students.

Six Australian middle school students were part of the study that investigated students' understanding of optics during the period of three years (Year 10 – 12) (Hubber, 2006). Over the years some of the students developed hybrid models of light, but some of them abandoned their previous models because those models could not explain new phenomena (i.e. diffraction, refraction, different colours). Hubber noted that students preferred different models of light when explaining different phenomena.

Research goal

The goal of this work is to create a diagnostic instrument for wave optics – the Conceptual test on wave optics (CTWO). Diagnostic instruments aimed at assessing conceptual understanding of students are important both for research and teaching purposes. They are mostly constructed in a multiple-choice format that enables easy administration to a large number of students.

Rasch analysis (Rasch, 1960) is a valuable tool which enables thorough quality control of the constructed test, its design and its functioning, as well as the functioning of its individual items. One of the most important uses of the Rasch model is to help guide test and survey construction and evaluate their functioning. Liu (Liu, 2010) suggests the following steps in test construction:

1. Define the construct that can be characterized by a linear attribute;
2. Identify the behaviors corresponding to different levels of the defined construct;
3. Define the outcome space of behaviors (item pool);
4. Field-test with a representative sample of the target population;
5. Conduct Rasch modeling;
6. Review item fit statistics and revise items if necessary;
7. Review the Wright map and add/delete items if necessary;
8. Repeat (4) to (7) until a set of items fit the Rasch model and define a scale; 9. Establish validity and reliability claims for the measurement instrument; 10. Develop documentation for the measurement instrument. A clear statement of the research questions the study is aiming to answer.

An insight into students' reasoning is important for measuring student conceptual understanding. In the diagnostic instrument it could be obtained in two ways: the answer and reasoning for it are offered in a single item (one-tier) or the answer and reasoning are offered in two separate items (two-tier). Some of the basic assumptions of the Rasch model are test unidimensionality and local independence of items. In two tier tests both assumptions are typically violated, so the Rasch analysis of the test could either produce distorted measures (tiers treated as separate items) or have the precision of the obtained measures reduced in half (two tiers combined into one polytomous item lead to halved number of items) (Baghaei, 2008). This study will attempt to evaluate student reasoning about wave optics using multiple - choice items that contain both answer and reasoning in a single tier, to avoid local dependence issues and allow a larger number of items.

Research questions of the study

The research questions this study is aiming to answer are:

1. What difficulties about wave optics phenomena do Croatian and Austrian secondary school students have?
2. How prevalent are the difficulties about wave optics phenomena among Croatian and Austrian secondary school students?

Research design, methodology and methods

This study will attempt to determine the difficulties that secondary school students have regarding wave optics. The first part of the study is of qualitative nature and its purpose is to give us an insight in difficulties that Croatian and Austrian students have concerning wave optics. The qualitative part, that will answer the first research question, has already been conducted in the form of semi-structured demonstration interviews. The identified difficulties that students expressed in the interviews helped us to create items for the quantitative part of the study, that will answer the second research question. This part will be conducted with the help of the multiple-choice test on wave optics (CWTO). The construction and validation of CTWO is still in progress.

Data collection and analysis

In the first part of the study 27 final year secondary school students from Croatia and 6 secondary school students from Austria took part in semi-structured demonstration interviews. Demonstration interviews are a common method in physics educational research (Ambrose et al, 1999, McDermott and Shaffer, 1992). It is a dialogue between a researcher and a student(s) based upon a simple demonstration experiments (McDermott and Shaffer, 1992). Students are usually asked for their prediction of outcome of a certain experiment and their explanation of observed outcome.

All students that participated in the study were volunteers and had grades at a mean (good) or above the mean (very good and excellent) at Physics in the previous year. All interviews with students lasted around 55 minutes. The interviews were audiotaped, transcribed and analysed.

Four demonstration experiments were prepared for the interviews, together with accompanying questions to probe students' conceptual understanding of wave optics. The experimental setup was shown to the students and then they were asked for prediction what would they see on the screen (after the laser light passes two narrow slits/optical grating/single slit) in words and drawings. Afterwards, they were asked for their observations (in words and drawings) and for their explanations of observed phenomena. Students were not corrected if they gave wrong predictions or explanations. In that case they were then asked other questions to give a better insight into their reasoning.

The interviewed students expressed some already known difficulties regarding wave optics, but some new difficulties were found, especially regarding polarisation of light. Some differences were found between Croatian and Austrian sample, especially about the nature of light.

In the second part of the study a new instrument (CTWO) will be used. CTWO is still in construction, but it will probe these five educational outcomes:

1. Apply basic wave concepts in the context of wave optics (wavelength, frequency, amplitude, period, wave fronts, wave speed, path difference, concept of coherent light sources).
2. Explain and analyse interference of light from two slits (Young's experiment), apply the interference rule.
3. Explain and analyse diffraction of light on a single slit and apply Huygens' principle.
4. Explain and analyse interference of light and dispersion of white light on an optical grating.
5. Describe polarisation of light after the light passed through a polarizer or reflected off a transparent optical medium.

Until now there were 6 cycles of item testing, in which more than 60 multiple-choice items were used. More than 400 secondary school students and ca. 100 first-year university students in Croatia took the test by now. One cycle of testing was done in Vienna, Austria, too, but the sample of secondary school students there was rather small (61 students).
The analysis of students' results on CTWO was performed using Rasch analysis, with Winsteps software (Linacre, 2006). Winsteps performs a logistic transformation of the raw scores of persons and items (p-values of students and items), and in this way nonlinear raw scores are transformed in linear measures of student ability and item difficulty. After each cycle, items that performed poorly were improved or completely omitted. Some other items were added for another cycle of item testing.

The most recent cycle of testing the CTWO was done in October 2019. 71 Croatian secondary school students took the new version of CTWO, right after their regular school instructions, but before the school test. This version of CTWO contained 30 items. The item – person map of this cycle is shown in Figure 1.

The average score that the students obtained in this cycle was 42,5%. The Cronbach alpha of the test was 0,61. There is a gap between items N3 and N21, meaning that CTWO still lacks easier items.

New cycles of testing the CTWO are planned for this school year (2019/20) both in Croatia and Austria.

After the well-functioning test of ca. 25 items is obtained, the final testing will be done both in Croatia and in Austria. The results will then be compared and discussed.

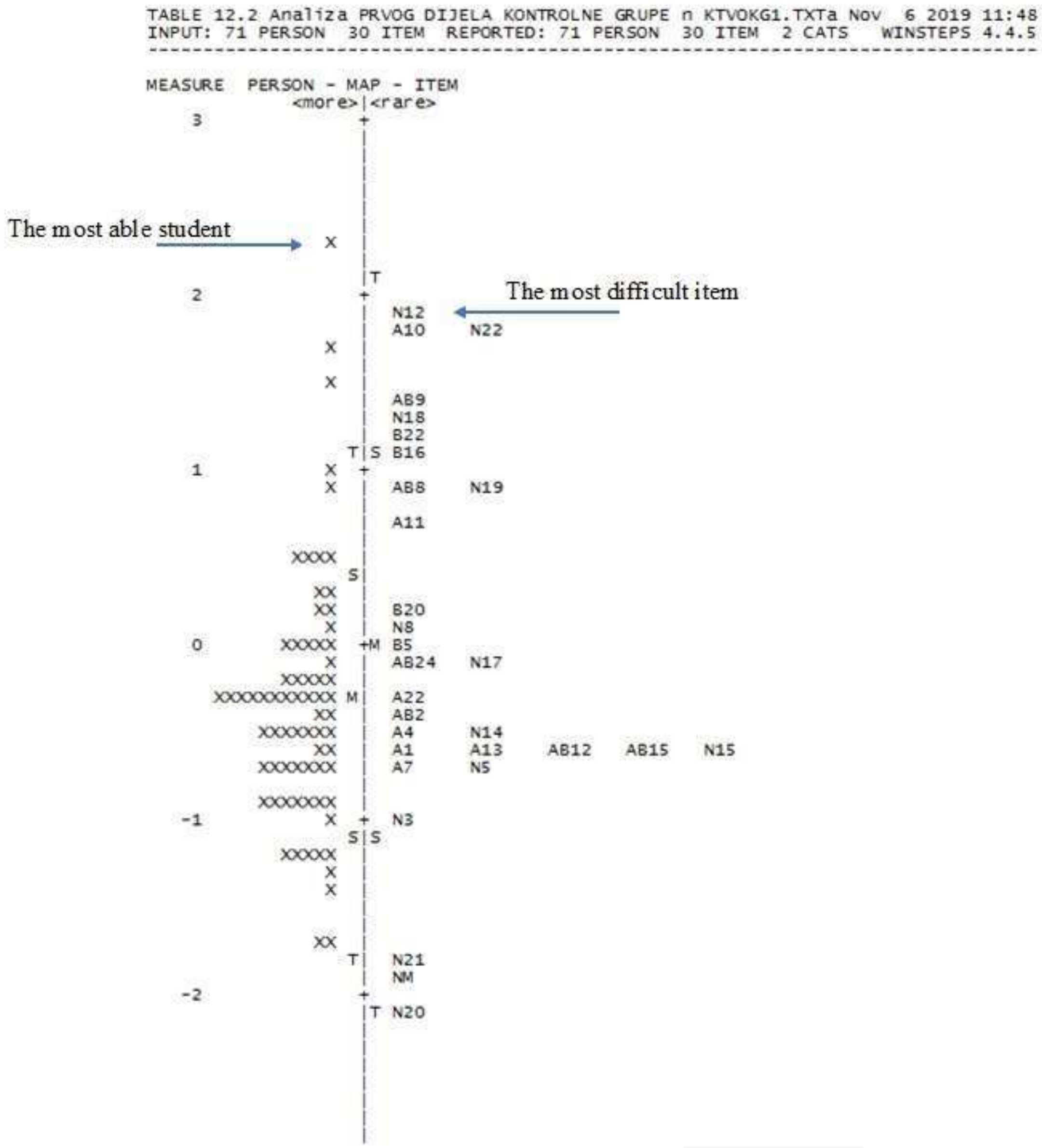

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TABLE 12.2 Analiza PRVOG DIJELA KONTROLNE GRUPE n KTVOKG1.TXTa Nov  6 2019 11:48
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                X  |
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                   |  N18
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               XX  |  B20
                X  |  N8
    0       XXXXX  +M B5
                X  |  AB24   N17
            XXXXX  |
      XXXXXXXXXXX M|  A22
               XX  |  AB2
          XXXXXXX  |  A4     N14
               XX  |  A1     A13    AB12   AB15   N15
          XXXXXXX  |  A7     N5
                   |
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   -1           X  +  N3
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Figure 1. Wrights map (item-person map) for the most recent cycle of testing the CTWO.

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A study of use of models in physics: Pedagogical practice and philosophical perspectives

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Abstract

This study explores the use of models and modelling in school physics lessons through the lens of contemporary perspectives towards models drawn from philosophy of science viz. syntactic, semantic, models as mediators, and models as artefacts. In doing so, the study not only seeks to develop empirically supported theoretical understanding of how models are used in actual school physics lessons, but also aims to transfer the insights thus gained into the theoretical discussions about nature of models. The participants are five A-level physics teachers and their students from two schools in London. Data is generated through video-recording of lessons and interviews with the participating teachers and some of their students. The analysis of the video data is carried out in iterative interpretative manner. The analytical framework consists of identifying and establishing ways to associate models-in-practice with models-in-theory.

Introduction

This research investigates key stage 5 physics lessons in two London schools to understand the incorporation of models and modelling in physics pedagogical practice in terms of various approaches towards models developed in the domain of philosophy of science. This investigation would also attempt to explore how the philosophical discussions may be informed by the pedagogical practice. In what follows, first, I describe the literature review thereby charting the emergence of the research gap and the research questions, followed by a brief description of methodology. Finally, I share some preliminary data analysis.

Literature Review

Models and modelling in science pedagogy

There is a rich tradition of studying the pedagogical practice, in particular the actual science lessons, with regard to modelling. The aims for these studies have been diverse (Oh and Oh, 2011; Gilbert and Justi, 2016), and the underlying theoretical frameworks form a diverse set, too – modelling cycles (e.g., Williams and Clement, 2015), teachers' professional growth (e.g., Justi and van Driel, 2005), focus on learning environments (e.g., Crawford and Cullin, 2004; and Windschitl, Thompson and Braaten, 2008), and syllabus structure (e.g., Henze, van Driel and Verloop, 2008). Hardly any of the studies appear to have the motivation or theoretical framework rooted directly into the domain of philosophy of science (e.g., Koponen, 2007). However, empirical investigations that attempt to situate the current theoretical discussions on models in the context of actual science lessons appear to be far and few.

With regard to the theoretical frameworks drawn from philosophy of science, I should note the approaches used in the research on nature of science (NOS). For instance, *family resemblance* framework by Irzik and Nola (2011, 2014) and the *whole science* framework by Allchin (2011, 2013) are two prominent frameworks (Gilbert and Justi, 2016) both rooted into the research in history and philosophy of science (HPS). Yet, neither is it clear to what extent these frameworks utilise different theoretical insights on model-conceptions, nor do these frameworks attempt to establish a bidirectionality between research in HPS and science education.

Oh and Oh (2011) took an overview of the literature on the nature of models and their classroom uses for the purpose of establishing what science teachers need to know about models. They investigated the conceptions that are common between the science education researchers and science philosophers in the following topics – model meaning, purposes of modelling, multiplicity of models, modifications in models, and classroom use of models. In order to support the teachers' use of models and modelling, it becomes essential to unpack each of these topics thoroughly which, in turn, would need an elaborate recourse to variety of theoretical perspectives towards models.

Models and modelling in philosophical research

Boumans and Leonelli (2013) describe two approaches to conduct philosophy of science as conceived by John Dupré. Philosophy-of-science in practice consists of the direct engagement 'with scientific research through interaction with scientists about philosophical problems (e.g. background assumptions, logical structure, implications of unexpected or even undesired test results) or/and collaborations on joint questions' (ibid., p. 260) which emerge at the intersection of scientific and philosophical inquiry.

On the other hand, philosophy of science-in-practice 'analyses science in the making, that is the daily practice of scientific research and everything that such practice entails (e.g. processes of inquiry, institutional settings and social dynamics among investigators)' (ibid., p. 260). The important point is that both the approaches conceive the philosophers' engagement with science in terms of what scientists do. This is borne by what the philosophers have done with regard to models and modelling. For instance, Cartwright (1999) supports the argument for the role of principled mathematical models in determining the domain of a theory by dissecting the seminal paper by Bardeen, Cooper and Schrieffer (BCS) on superconductivity. Knuuttila and Boon (2011) demonstrate the artefactual approach towards models by taking Sadi Carnot's construction of ideal heat engine. (For more such examples, please see, Giere, 1988; Morgan and Morrison, 1999; Suárez, 2009; Humphreys and Imbert, 2012).

Research gap and research questions

On the one hand, much of the educational research into models and modelling fails to explore the science-philosophical roots of models in science pedagogy. The attempts in pedagogical research to identify and characterise the teachers' and the students' views towards models typically do not extend to the stage of forming a theoretical understanding of what actually happens in classrooms. Consequently, an opportunity to develop a more thorough understanding of models in science lessons, and support that practice accordingly, is missed.

On the other hand the discussions in philosophy of science focus mostly on what scientists do and think about models, they hardly consider the other significant situation where models, or an understanding of the models, are developed and used extensively viz. science education. What sort of theoretical insights into models may we be ignoring by not considering science pedagogical practice? A more comprehensive and nuanced understanding of nature of models can hardly afford to miss science pedagogy from its scope because learners in school form a significant part of the wider community of scientific knowledge developers.

These considerations lead me to form the following research questions –

1. **How far can the use of models and modelling in physics lessons (key stage 5) be understood through contemporary theoretical perspectives on models in science?**
2. **How does the pedagogical use of models in physics lessons further contemporary theoretical perspectives on models in science?**
3. **How might theoretical perspectives on models and modelling inform practice in key stage 5 physics?**

I acknowledge the third question as a research question despite its non-empirical nature because (i) by making it a research question I intend to spend significant time and effort in answering it as opposed to considering it a mere tail end of the investigation, (ii) its speculative nature is counterbalanced by my plan to answer it by synthesis of evidence I construct in answering the first two questions, thereby making the answer to the third question a coherent and well-formed extension of the empirical investigation.

Methodology

Theoretical framework

I adopt the position of perspectival realism according to which scientific knowledge is epistemologically and methodologically perspectival (Massimi, 2017, 2018). My research is motivated by the desire to understand physics teaching through *contemporary* theoretical perspectives on models. By contemporary, I mean those perspectives which are widely recognised and discussed among the philosophers of science. The results of a search of the philosophical literature on scientific theories and models are tabulated in Appendix I. The table indicates that the perspectives widely identified and distinguished are *syntactic*, *semantic*, *models-as-mediators*, and *artefactual*. While these being not the only perspectives under discussion, the table demonstrates that the four perspectives are among the most widely recognised ones. This is the chief reason for choosing these perspectives. Appendix I offers further reasons for selecting these perspectives.

Syntactic perspective

On this view, a theory is understood in syntactical manner whereby a theory is broken down in 3 ways – terms (or the vocabulary of the theory), sentences, and languages (Winther, 2016). Per this view, at best, a model is 'just a system of semantic rules that interpret the abstract calculus and the study of a model amounts to scrutinizing the semantics of a scientific language' (Frigg and Hartmann, 2017).

Semantic perspective

On this account of scientific theories, theory is constructed by defining the class of models which the theory is intended to describe or explain. Thus, 'the claims made by the theory are true in the model' and this becomes a necessary condition for a model to be a model of that theory (Morrison and Morgan, 1999, p. 3).

There are three major variations of this view each offering a different way of conceptualising theory interpretation (Winther, 2016) – (i) a hierarchy of models, (ii) isomorphism (van Fraassen, 1980, 2008; Suppes, 2002; Suarez, 2003), and (iii) similarity (1988, 2004).

Mediator perspective

This framework consists of the argument which construes models as having certain degree of autonomy from theory as well as data (Morgan and Morrison, 1999; Frigg and Hartmann, 2017). This autonomy enables models to mediate between high level theory and real world phenomena/systems. This framework is built on four pillars in relation to models – construction, functioning, representation, and learning from models (Morrison, 1999; Morrison and Morgan, 1999).

Artefactual perspective

This perspective brings the spotlight on the materiality of models (Knuuttila, 2005a, 2005b, 2011), and proposes to consider models as epistemic artefacts, which are 'intentionally constructed things that are materialized in some medium and used in our epistemic endeavours in a multitude of ways' (Knuuttila, 2005a, p. 1266). The artefactual nature of models can be understood via their five characteristics of models – (1) the constrained design of models, (2) non-transparency of the representational means, (3) results-orientedness, (4) concrete manipulability, and (5) distributed justification (Knuuttila, 2011).

Methods

The following table demonstrates the choice of methods and how each of them supports in answering the *empirical* research questions –

Sr. No.	Methods	Research Questions (RQ) they support
1.	Video-recording of lessons	RQ 1 via generation of a large number of lesson observations having enough variety of models and the associated discussions, and observing the different ways by which teachers develop the discussions about and around the models. This develops data for the "use of models and modelling in physics lessons" part of the RQ.
		RQ 2 via creation of empirical evidence to support the theoretical discussions in this question.

2.	Teacher interviews	RQ 1 by eliciting teachers' decision-making process with regard to models they used, for instance, why they chose a particular model, why they used it in a particular way, why they focused on particular aspects of a model and so forth. The decision-making process in modelling is an important aspect to which the theoretical perspectives attend. RQ 2 by eliciting teachers' views towards models, and why and how they use them in lessons. This would help in bringing the pedagogical angle to the theoretical discussions.
3.	Student interviews	RQ 2 by understanding the students' views towards their use of models.

Participants:

Five physics teachers total and the students in their classes (Year 12 and 13) from two schools in London selected by convenience sampling (Bryman, 2008).

Duration:

Autumn and Spring terms at both the schools.

Please refer to the **Appendix II** for the status of the research at the time of writing this synopsis.

Data analysis

The aim for the analysis is to explore how the theoretical perspectives towards models and pedagogical practice correspond to each other, i.e., seeking an association between the different theoretical perspectives towards models and actual happenings during lessons. This is done by conducting an interpretative analysis built on (i) identification of a model in the lesson, (ii) identifying the characteristics of its use/development in the lesson, and (iii) associating those characteristics in terms of aspects of the four perspectives from the theoretical framework.

The development of the analytical framework goes hand in hand with the data generation through video recordings. The analysis is iterative in which the initial analysis based on the theoretical framework is followed by its application to the video recordings, and then the insights gained in this process inform the analytical process itself. I use NVivo for managing and working with the video-data.

Illustration of analysis

A small part of this iteration is illustrated below by considering a snippet of a video recording. This snippet consists of a teacher (**TG13**) *summarising* (evident from the transcript below) the concept of electric field.

(i) Identification of a model:

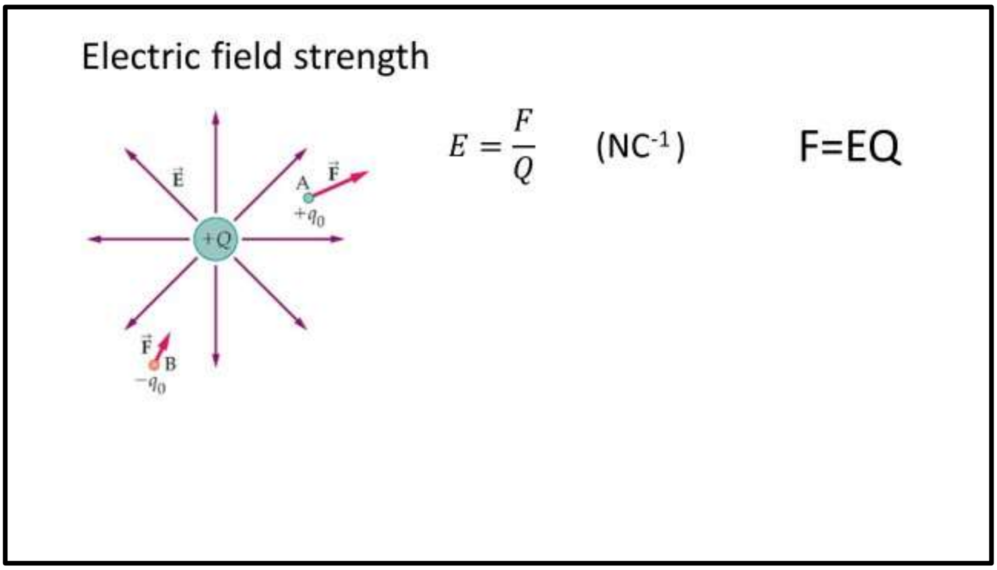
I consider this to be a discussion on a model because the charged particle (which is represented on the whiteboard by a small circle with + sign inside it) is an idealised version of reality. This idealisation is evident in the considerations viz. the particle is a point particle, and it is considered static in vacuum in the absence of any external field. In addition, the picture accompanying the discussion (ref. Fig.1 below) has the heading "Electric field strength" and consists of outwardly radiating arrows drawn from a small circle with + sign inside it. This indicates the electric field is diagrammatically (arrows) represented, which is a feature of representation of a model. Moreover, the arrows are shown in the two dimensions formed by the plane of the whiteboard. This indicates that the field representation is idealised by omission of one dimension of its 3 dimensional nature. Therefore, both the charged particle and the associated electric field are identified as models.

(ii) Identifying its characteristics:

The electric field strength was discussed in the context of the summary of the topic. This is determined by the following piece of transcript:

TG13: This is the last formal lesson for the electric fields and I am going to just summarise what we learnt about this field and then draw some parallel between gravitational field and electric field.

(*The following picture is on the board*)



Electric field strength

$E = \frac{F}{Q}$ (NC^{-1}) F=EQ

Fig. 1

TG13: So e fields so we have a charge would be quite happy with it plus charge a test charge which is positive and we know the e field *(touches the finger on the board in the region of the diagram)* is a function of the force and the charge that's that I think *(keeps making a circling motion by his finger around the mathematical formula on the right)* conceptually that's probably an easy way to think about it because it's a product the force involved is a product of e field and the charge the bigger the e field the bigger the charge (*addresses a student*) you happy with this yeah but then you are typically asked to work out an e field

(*points to the equation in the middle*) so that's like q

I make following remarks –

(1) This transcript indicates that the electric field is represented in two distinct ways – a pictorial/graphic representation and mathematical symbolic formalism. The accompanying discussion does not mention or describe explicitly and specifically the purpose of defining the concept of electric field using either of the representations. The physical significance or interpretation of the concept of electric field is not mentioned. (2) Electric field is discussed solely using the some other conceptual terms such as "force", and "charge". Its connection with other concepts is described in terms it being "a function of force and the charge".

(3) In the pictorial representation, the charge from which the electric field is seen emanating is labelled "Q". This is also the same letter (with capitalisation) used in the mathematical relations between electric field E and the force F, i.e., there is no symbolic distinction between the charge that produces the electric field and the charge on which the field acts.

Now I use these remarks to uncover the underlying theoretical approach.

(iii) Associating with the theoretical perspectives:

These remarks indicate that the classroom summary of the concept of electric field is centred on the mathematical formalism or the calculus of the theory of electrostatics. The last two points highlight the absence of the physical interpretation of the theoretical terms. Particularly, the remark no. (3) above indicates the possibility that the symbols may be used only as a placeholder for the generic term “charge”, rather than a meaning-carrying entity which affords distinction between two different charges i.e. one that produces the field and the one which experiences it by way of electrostatic (Coulomb’s) force. Whether the use of the same letter is a typographical error or otherwise could be determined during the interview with the teacher.

This discussion implies that the treatment of the model tended to be more of a syntactic manner, whereby the language consisted of theoretical terms and their logical i.e. the mathematical relations. Thus, the discussion mainly consisted of theoretical sentences with the absence of any observational statements and correspondence rules, which would connect the theoretical terms with the observations. Per the syntactic perspective, this description stands for the “uninterpreted theory” part of the structure of scientific knowledge.

What I intend to gain in the ESERA Summer School 2020

My primary motivation in attending the summer school is to gain insights and inputs from my peers and more experienced researchers –

(i) to develop a more robust analytical framework that would allow me to investigate the large variety of models in the videos I have recorded in a more efficient manner
(ii) to identify the most appropriate way to use the data analysis to feed back into theoretical discussions i.e. the second research question
(iii) to develop a better understanding of the ways to construct a reasonable discussion on the third research question
(iv) to identify gaps or inadequacies in the methodology so that I could rectify them.

Appendix I

Why these four perspectives?

My research is motivated by the desire to understand physics teaching through contemporary theoretical perspectives on models. By contemporary, I mean those perspectives which are widely recognised and discussed among the philosophers of science. In order to identify those, the best place would be the literature related to philosophical discussions on models. The results of a search of the philosophical literature on scientific theories and models are tabulated below. Broadly the literature resources are of three types – books and chapters from edited compilations (No. 1 to 17), peer-reviewed review articles (No. 18 to 21), and entries in handbooks and encyclopaedias (No. 22 to 30). The Reference column lists the authors in a manner to make them easy to find in the bibliography. The last column lists the underlying philosophical perspectives towards models as expressed in each text. The listed terms are accompanied by brackets of my own, which indicate which one of the four perspectives the textual terms relate to. I infer this relation by connecting the terms in the text with the more elaborate discussions on the four perspectives elsewhere. For instance, referring to No. 9, logic-based account associated with Vienna Circle actually refers to the syntactic perspective (Winther, 2016).

Sr No.	Title of the resource	Reference	Philosophical underpinnings of models discussed in the text
1.	Scientific Models in Philosophy of Science	Bailer-Jones (2009)	Logical empiricism (i.e. syntactic), semantic
2.	How To Do Science With Models: A Philosophical Primer	Gelfert (2015)	Syntactic, semantic, fictionalism, mediators, epistemic *active* tools (i.e. artfactual)
3.	Simulation and Similarity: Using Models to Understand the World	Weisberg (2013)	Semantic, weighted featurematching account of similarity
4.	Modelling-based Teaching in Science Education	Gilbert, Justi (2016)	Syntactic, semantic, mediator, artefactual

5.	Science and Partial Truth: A Unitary Approach to Models and Scientific Reasoning	da Costa, French (2003)	Semantic, partial structures or partial isomorphism.
6.	Against Fictionalism (from the book ModelBased Reasoning in Science and Technology: Theoretical and Cognitive Issues)	Woods (2014)	Fictionalism
7.	How Scientific Models Differ from Works of Fiction (from the book ModelBased Reasoning in Science and Technology: Theoretical and Cognitive Issues)	Portides (2014)	Fictionalism, models as epistemic agents through idealizations (this is one of the core arguments in the mediator approach)
8.	Bohr's Theory of the Hydrogen Atom: A Selective Realist Interpretation (from the book ModelBased Reasoning in Science and Technology: Theoretical and Cognitive Issues)	Ghins (2014)	Structuralist view of models with the focus on homomorphic representation (i.e. a version of the semantic perspective),

9.	Introduction (from the book Models as Mediators: Perspectives on Natural and Social Science)	Morrison, Morgan (1999)	Syntactic, semantic, autonomy of models (i.e. part of the mediator perspective)

15.	Similarity and Dimensional Analysis (from the book Philosophy of Technology and Engineering Sciences)	Sterrett (2009)	Geometric similarity
16.	Scientific Concepts in the Engineering Sciences: Epistemic Tools for Creating and Intervening with Phenomena (from the book Scientific Concepts and Investigative Practice)	Boon (2012)	Epistemic tools (i.e. artefactual)
17.	Understanding by Modeling: An Objectual Approach (from the book Scientific Understanding: Philosophical Perspectives)	Knuuttila, Merz (2009)	Objectual (i.e. artefactual)
18.	Models, Theories, and Structures: Thirty Years on	da Costa, French (2000)	Received view, semantic, autonomy of models (i.e. mediator)
19.	What Teachers of Science Need to Know about Models: An overview	Oh, Oh (2011)	Models as a representation, mediator

20.	Models and Modelling in Physics Education: A Critical Re-analysis of Philosophical Underpinnings and Suggestions for Revisions	Koponen (2007)	Semantic, mediator
21.	What Are Models and Why Do We Need Them?	Grandy (2003)	Received view, semantic
22.	Models (entry in The Routledge Companion to Philosophy of Science)	Portides (2013)	Syntactic, semantic, mediator
23.	Models and Theories (entry in The Oxford Handbook of Philosophy of Science)	Morrison (2016)	Syntactic, semantic, poststructuralist/pragmatic
24.	The Ontology of Models (entry in Springer Handbook of Model-based Science)	Gelfert (2017)	Models as functional entities with informational and pragmatic views of representation function – discussed in terms of analogies and metaphors, folk ontology, fictions, syntactic, semantic, partial structures, mediators, artefacts.
25.	Models and Theories (entry in Springer Handbook of Model-based Science)	Portides (2017)	Received view, semantic view

26.	Models and Representation (entry in Springer Handbook of Model-based Science)	Frigg, Nguyen (2017a)	Representation on basis of following conceptions – Similarity, structural, inferential, fictional, DEKI account of representation-as.
27.	Structures of Scientific Theories	Craver (2002)	Syntactic, semantic,
	(entry in The Blakwell Guide to the Philosophy of Science)		
28.	Models, Metaphors and Analogies (entry in The Blakwell Guide to the Philosophy of Science)	Bailer-Jones (2002)	No specific philosophical perspective
29.	Models in Science (entry in Stanford Encyclopedia of Philosophy)	Frigg, Hartmann (2017)	Based on ontological considerations - physical objects, fictional objects, settheoretic structures, descriptions, equations, or combinations of some of these. Based on theory-model relationship - syntactic, semantic, autonomous agents
30.	The Structure of Scientific Theories (entry in Stanford Encyclopedia of Philosophy)	Winther (2016)	Syntactic, semantic, pragmatic (Nancy Cartwright's views further developed into the mediator approach)

The table above offers evidence from literature that the four perspectives are widely identified and distinguished. Certainly, these are not the only perspectives under discussion. However, the table demonstrates that the four perspectives appear to be among the most widely recognised ones, if not the most. This is one of the major reasons for choosing these perspectives.

Furthermore, the basis for development of syntactic and semantic views is the theory-model relationship. However, the mediator and artefactual approaches offer a framework for understanding of models which is not focused on the theory-model relationship. To be more precise, the artefactual approach is more de-focussed from the theory-model relationship than the mediator one. In other words, the difference in basis for the development of each is what sets these approaches apart. Therefore, the choice of these four perspectives not only covers different ways to look at models, they also cover two basis for conceptualising these approaches towards models as explicated below –

a. Syntactic, semantic and mediator: The basis of conceptualisation is theorymodel relationship with the syntactic and semantic being at two extreme ends of the spectrum of characterisation of that relationship (Frigg and Hartmann, 2017). The mediator approach is based on the model-theory relationship through its emphasis on independence of models from both theory and data.
b. Artefact: The basis of conceptualisation is the materiality of models leading to models being understood as epistemic artefacts. This approach does not require any direct recourse to model-theory relationship for its conceptualisation.

Consequently, by considering these four perspectives, the hope is that the discussion would pave way for further cogitations about the very basis used for development of each perspective, i.e., not only what each perspective entails in classroom but also about the origins of the conceptualisation of the perspectives.

Appendix II

This schedule gives the status of the research so far and the future plan of action.

Activity	School	Academic Year			
		Sept 2018 –Aug 2019	Sept 2019 – Aug 2020	Sept 2020 – Aug 2021	Comments
Lesson observation	School 1 (2 teachers)	Nov 2018 – Apr 2019 (1st and 2nd term)			
	School 2 (3 teachers)		Nov 2019 – Apr 2020 (1st an 2nd Term)		
Interviews with teachers	School 1		Feb 2020		Some time is allowed between the end of lesson observations and the teachers' interviews for analysing the video

					recordings. The interview schedules would be determined on the basis of these inputs.
	School 2		May 2020		Same as above.
Interviews with students	School 1		Feb 2020		
	School 2		May 2020		
Data Analysis		Started on Jan 2019		End by Dec 2020	This has already started with the data coming in from lesson observations in School 1. The process is iterative and will be simultaneous with the data generation.
Thesis writing	Started in 2018			Final version	Writing is an ongoing process.
				by Mar 2021	

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Productive representational errors – Investigating the potential of alternative mechanistic reactions in learning organic chemistry

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Abstract

Students have various problems with decoding representations, inferring implicit properties and causal reasoning. Moreover, studies revealed that students struggle with connecting representations and chemical concepts and thus have fragmented understanding of fundamental chemical concepts in organic chemistry, such as nucleophilicity and electrophilicity. As a result, students have problems predicting the outcome of reactions through balancing potential mechanistic pathways. Therefore, my current research project puts emphasis on confronting students with alternative mechanistic reactions (AMR). The AMRs are focused on the chemical concept of nucleophilicity and electrophilicity. The objectives of my research project are to answer qualitatively 1.) what type of mechanistic features do students use when reasoning about nucleophilicity and electrophilicity, 2.) how they connect those features to make a claim about the plausibility, and based on these initial diagnostic questions 3.) to develop an instructional scaffold, and 4.) to test quantitatively if students' mechanistic features improves through an explicit analysis of AMRs.

Introduction and state of research

What do organic representations convey?

The chemical language is internationally understandable because of the standardized symbolism and representations such as structural formulas, diagrams and mechanisms [1]. In organic chemistry, structural formulas and mechanisms are clearly more ubiquitous than mathematical equations and thus representations of structures and mechanisms carry explanatory power. A typical mechanism is conceptualized and consists of mechanistic features: entities, their properties and the activities in which the entities are engaged in [2]. In the first instance, representations allow to determine explicit properties since these properties can be perceived immediately. Implicit properties and various related chemical concepts (e.g. hyperconjugation or electronegativity) cannot be identified immediately and have to be linked to the representations [3]. For this reason, evaluating and interpreting representations is a fundamental ability in chemistry that students need to develop [3].

Students' understanding of explicit and implicit aspects

Moreover, students often struggle to distinguish between explicit and implicit aspects of representations. Therefore, students are often unable to see the meaning beyond representations [4]. Students are focusing on surface features of representations. That is why their intuitive reasoning is often guided by these features. The problem is that the explicit surface characteristics certainly are easier to be recognized yet not necessarily relevant [5]. Therefore, it is one of the main challenges in learning and teaching chemistry to make students aware of the invisible. Students' reasoning often contains little mechanistic information and is focused on surface or "atomic" changes in chemical reactions. They tend to take explicit features of representations into consideration, rather than reasoning about implicit properties or influencing variables.[5-9] In contrast, experts attribute functions to representations being structural formulas or mechanisms allowing them to make use of information that is embedded in the representation [4].

Students use of heuristics strategies

Evans [10] divided reasoning in two different types that influence human decision-making. Type 1 reasoning is intuitive and fast in the decision-making process. Whereas, type 2 reasoning is characterized by analytical thinking that may be time-consuming [10]. Students often use type 1 reasoning, which is mainly represented by the documented usage of heuristic strategies [11]. A heuristic is a practical intuition-based method for problem-solving. Talanquer mentioned that heuristics are "responsible for systematic errors in judgement, particularly when relevant decision-making cues are implicit rather than explicit or unknown to people" [5]. Hence, heuristics are useful tools for quick decision-making but without a required fundamental knowledge, it is possible that heuristics indicate misconceptions [12]. Furthermore, students use heuristics and provide explanations without even understanding the underlying chemical concepts [13]. Nevertheless, it is not the purpose to eliminate intuitive thinking like heuristics out of classes, but rather fostering students' awareness for their own mechanistic features when using and interpreting reactions [14].

Students' conceptual understanding

It is commonly known that students have various difficulties with grasping chemical concepts [8, 15-17]. Nucleophilicity and electrophilicity are prominent chemical concepts susceptible for misconceptions, for instance the distinction between a Brønsted-Lowry base and a nucleophile and a Brønsted-Lowry acid and an electrophile. Moreover, students focus on explicit characteristics as negative (nucleophile) and positive (electrophile) charges but neglect partial charges, orbitals, electron pairs or possible reagents. For that reason, many researchers focused on students' misconceptions about nucleophilicity and electrophilicity [6-7, 18-19]. Anzovino and Bretz [6] exposed that students' problems with nucleophilicity and electrophilicity do not derive from a lack of defining the term. The participants were able to define the terms, but they struggled to recognize a nucleophile in the respective context. Consequently, in reaction settings students were not capable to identify nucleophiles and electrophiles even when they partly defined these terms. Moreover, students refer to deterministic explanations which means that they argue with specific forces that foster reagents to react to specific products [20].

Learning with errors

To foster students' mechanistic features, the nature of their individual solving approaches towards typical mechanistic reactions must be investigated first. Tanner and Allen mentioned that "students' 'wrong' answers may be our best tool in crafting learning experiences that will move them toward the 'right' answers" [21]. Moreover, Wong and Lim [22] pointed out that the usage of errors in teaching and learning can be manifold. However, most of the psychological research is focusing on detecting and correcting errors [23-24]. In the current literature of chemistry education, identifying errors is mostly used to recognize students' conceptions about various topics [15, 18, 25]. Coppola and Pontrello [26] as well as Graulich [12] brought up that there is a substantial gap in literature about using errors as a learning tool as well as the approach of learning with errors in chemistry.

Objectives of my research project

My research project follows the ideas of former research and puts emphasis on confronting students with alternative mechanistic reactions (AMRs). There has not been thorough research conducted in the field of "thinking in alternatives" yet. Caspari considered that backward-oriented chaining to compare subsequent parts of mechanisms to make a decision about prior parts is a possibility to think about alternatives mechanistically [27]. In traditional learning environments – as lectures or plenary talks – students have little opportunities to think in alternatives. That may be due to the fact that traditional settings convey a great amount of information in a brief time span. Therefore, a qualitative study is conducted first to act as a diagnosis tool to ascertain how students reason about alternative mechanistic reactions, what mechanistic features they use and how they connect these features when making a claim in order to be able to design an appropriate instructional scaffold. Building upon these results, a quantitative study will be conducted to investigate if supporting students to reflect about alternative mechanistic reactions improves their use of productive mechanistic features and engages them to build appropriate claims.

Thereby, I am not only analyzing students' mechanistic features, but I also consider how students connect those features to make a claim about the plausibility of AMRs. The use of mechanistic features may characterize students' solving approaches in order to derive information for an instructional scaffold to support students' conceptual understanding. The AMRs are focused on nucleophilicity and electrophilicity because they are ubiquitous in all organic chemistry courses. To confront students with AMRs, students must be engaged in recognizing and reflecting on these alternative pathways that are considered to be correct or erroneous. Students often struggle with assessing the usage of appropriate solving approaches. Therefore, it is helpful to simultaneously support them with metacognitive monitoring techniques [28] such as an instructional scaffold.

As organic chemistry is a process-oriented field that often require complex, multi-variate reasoning [29-30], it is part of type 2 reasoning. Therefore, reasoning may be timeconsuming but leads to a deeper understanding of chemical concepts. Even though students tend to use simple heuristic strategies that minimize the amount of cognitive effort, analytical, and slow reasoning may allow to reason about underlying chemical processes to predict unknown reactions and alternative pathways. Accordingly, students have to be aware that both, explicit and implicit features, need to be included in the decision-making process. However, meaningful strategies - as thinking about alternative mechanistic reactions – require processing and application of various information in the working memory which makes it cognitively demanding and rather slow.[31] In order to investigate the potential of AMRs the following research questions arise.

Research questions

Qualitative study:

1. What type of mechanistic features do students use when they are confronted with alternative mechanistic reactions?
2. How do students connect mechanistic features to make a claim about the plausibility of alternative mechanistic reactions?

Based on the results of the qualitative study, an instructional scaffold will be created to test quantitatively if thinking in alternatives can be instructed and if it supports students' mechanistic features in the desired concepts. Thereby, the effect of learning with AMRs on students' features will be measured [32]. That leads us to the third research question.

Quantitative study:

3. Does students' use of mechanistic features improve through an explicit analysis of alternative mechanistic reactions about nucleophilicity and electrophilicity?

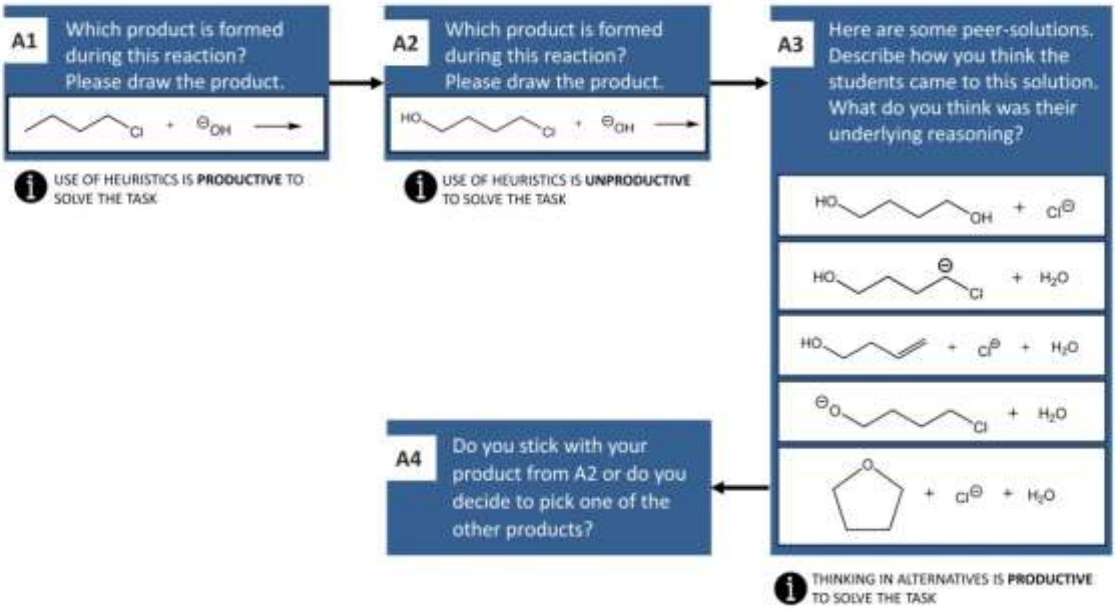
The overall goal of my research project is to contribute to the pending question how learning and teaching organic chemistry can improve students' focus on reactions by analyzing and interpreting AMRs. My research follows an explanatory sequential mixed methods study design [33]. First, a qualitative study was conducted to explore students' reasoning. It will be qualitatively analyzed what mechanistic features students use and how they connect these features. Based on students’ productive reasoning, an instructional scaffold will be designed. This scaffold will be used in the follow-up quantitative study.

Description of the working plan

Figure 1. Time table of the working plan.

Designing the qualitative study

To determine mechanistic features while using AMRs in organic chemistry, a qualitative study was performed. Thereby, appropriate tasks and prompts were prepared to detect mechanistic features while using AMRs (cf. figure 2 for an overview of task A). Based on the idea of cognitive dissonances [34] students first get confronted with familiar tasks that are normally discussed in introductory organic chemistry courses. This is not only meant as a warmup to get students comfortable with the interview scaffold but to guarantee an easy success of rote memorization because students may use intuitive heuristics [9, 35]. After that, students are actively compelled to make errors. Thereby, the following subtask differs only in a few features on the surface level to provoke the use of the same solving approach which is not productive. In the next subtask, they receive AMRs which are considered to induce a cognitive dissonance to guide them into an analytical reasoning [5]. This is the crucial step that may lead to replace intuitive approaches with analytical processes because students have to take an outsiders’ perspective [36]. With the induced cognitive dissonances, which cause discomfort for students that lead them to defend or correct their decision [37], students mechanistic features may become apparent through contrasting students’ solving approaches. Thereby, it is possible to diagnose how students are reasoning about AMRs, productive and unproductive mechanistic features become apparent and can be characterized to receive information about the support students need to improve their awareness. By that, it is tested what kind of input students would need to successfully work with AMRs independently.



A1 Which product is formed during this reaction? Please draw the product.

USE OF HEURISTICS IS **PRODUCTIVE** TO SOLVE THE TASK

A2 Which product is formed during this reaction? Please draw the product.

USE OF HEURISTICS IS **UNPRODUCTIVE** TO SOLVE THE TASK

A3 Here are some peer-solutions. Describe how you think the students came to this solution. What do you think was their underlying reasoning?

THINKING IN ALTERNATIVES IS **PRODUCTIVE** TO SOLVE THE TASK

A4 Do you stick with your product from A2 or do you decide to pick one of the other products?

Figure 2. Prompts and product cards for task A.

Data collection of the qualitative study

In the qualitative study 29 students of the course “Organic Chemistry III” at a German university were recruited. During the individual interview, the participants received two tasks (A/B) that are based on the same principle and discussed several AMRs. I, as the interviewer, asked questions via a semi-structured protocol to gain insight into students’ reasoning when they are confronted with familiar and AMR tasks. The semi-structured interview is used to obtain comparable, reliable data [38]. Students were recorded and interviewed, and the verbal utterances were transcribed verbatim.

This is the current research status. The data analysis and coding of the data is currently underway and will be finished in spring 2020.

Data analysis of the qualitative study

Afterwards, the collected data will be analyzed with different foci. On the one hand, the data will be analyzed to detect 1.) what type of mechanistic features they are using when reasoning about nucleophilicity and electrophilicity. On the other hand, it will be analyzed to detect 2.) how they connect mechanistic features to make a claim about the plausibility of AMR tasks. Therefore, the data will be analyzed and coded with the program MAXQDA [39]. Students’ reasoning about nucleophilicity and electrophilicity will be coded through a qualitative content analysis to detect the different features [40]. The analysis further aims at characterizing specifically the features that are productive in students’ evaluation of the AMRs or unproductive, that do hinder students’ successful reasoning.

Designing the instructional scaffold

Based on the prior qualitative analysis, an instructional scaffold will be designed to address students' mechanistic features when solving AMRs. The tasks and more intensively an instructional scaffolding will be designed, based on the mechanistic features derived from the qualitative study. One can imagine that identifying properties first can slow down the decision-making process before collecting, weighing arguments and reaching a decision. This progressive approach can lead to a recognition of more implicit features to incorporate a greater number of variables [41]. Therefore, an appropriate scaffold will be constructed based on the analyzed data. It will address the collected mechanistic features. The instructional scaffold and the underlying hypothesis if students' mechanistic features improve through an explicit analysis of AMR tasks will be refined based on the qualitative results and then be tested quantitatively.

Piloting the pre- and post-test and the instructional scaffold

The tasks for the pre- and posttest will focus on the chemical concept of nucleophilicity and electrophilicity and the productive mechanistic features. During task design, there will be a special focus on assessing the underlying meaning, because through this way there is the chance to measure if the instructional scaffold improves students' mechanistic features rather than using terms about chemical concepts "as empty envelopes that held no further meaning" [12]. The tests will be composed of ordered multiple-choice to ensure a higher validity. Before conducting the quantitative study, both, the pre- and post-test and the instructional scaffold will be piloted with several students. After that, the pre- and post-test, wording and task design will be improved.

Data collection of the quantitative study [32]

The instructional scaffold will be tested quantitatively in order to measure the influence of using AMRs. Therefore, a pre- and posttest will be used, and the quantitative study will then be conducted with a sample of approximately 100 students, enrolled in an organic chemistry course. After completion of the pretest, students will be randomly assigned to the two groups – a guided and an unguided one. It is currently planned that one group will receive AMRs with an instructional scaffold that is based on the qualitative results to support structuring in students' reasoning. The second group will receive AMRs without the aforementioned instructional scaffold and is therefore unguided. The instruction will be then followed by a posttest.

Data analysis of the quantitative study

The data collected in the pre- and posttest will be analyzed statistically with the program SPSS. Thereby, statistical evaluations about the impact of the instructional scaffold will be calculated including significances and effect sizes.

Finally, the analyzed qualitative and quantitative data will be compared. The results will be summarized and published to answer all asked research questions.

Current State of the project – data analysis

As already mentioned, the data collection of the qualitative study is completed. Currently, the data is transcribed verbatim. After a first brief data scan, it is possible to make a superficial claim that the participants often do not include chemical concepts in their explanation and moreover do not connect them, and rather follow their intuition. The participants consider AMRs mostly as erroneous. However, they cannot express thei underlying reasoning of their decision. Many participants experienced a cognitive conflict and changed their reasoning after discussing several AMRs, and realizing that they did not include chemical concepts in their explanation before. A more precise analysis and an in-depth coding scheme will be the next step, that should be finished in spring 2020.

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Performance of high school students in inquiry and argumentation practices in the context of food safety

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Abstract

This thesis project examines the epistemic knowledge performed by high school students in inquiry and argumentation practices in the context of food safety. Participants are students from 10th grade (15-16 years old) and 11th grade (16-17 years old). The intervention, designed for analysing students' performances in inquiry an argumentation and the epistemic knowledge involved, consisted of three tasks with different foci: two of them on socioscientific argumentation and the other one on both inquiry and argumentation. In this proposal, we focus on the analysis of one of the argumentation tasks, which consisted in a role-play game that set out an unsolved alimentary emergence. In particular, we examine the epistemic operations performed by students during the role play. The data are examined through discourse analysis. The preliminary findings suggest that students' performances focus on the epistemic practice of proposing knowledge, and to a lesser extent, on evaluating knowledge.

Keywords: Epistemic Practices; Food Safety; High School

Introduction

The purpose of this research is to analyse high school students' performances in the scientific practices of inquiry (analysis of scientific investigations) and argumentation (interpretation of data and evidence). Scientific practices are understood as those practices carried out to build, expand and refine knowledge (NRC, 2012). Three scientific practices are differentiated: inquiry, argumentation and modelling. In this study we only focus on the first two. The starting point for this research is the consideration of epistemic knowledge as key for an adequate development of scientific practices, understood as an array of understanding, practices, and motivations related to topics such as what counts as knowledge and how knowledge claims are justified (Chinn, Rineheart and Buckland, 2014). Addressing the educational context, the results of the PISA 2015 assessment (OECD, 2016) identified lower scores in secondary students in practical performances of investigation and argumentation, although they are considered essential for the apprentice of reasoned and active sciences (Osborne, 2014).

Epistemic knowledge has been studied in the last decades because its relation to the students' approaches to learning science, as well as to their performances of scientific reasoning (Yan et al., 2018; Yan and Tsai, 2010).

Epistemic knowledge can be examined in the form of epistemic practices, understood as the socially organized and interactionally accomplished ways that members of a group propose, communicate, evaluate, and legitimize knowledge claims (Kelly, 2008). According to Kelly and Licona (2018), epistemic practices are contextual, not static over time and field and time dependent. These authors suggest that there is not a limited set of epistemic practices, but they categorize them into four general dimensions associated to cognitive processes: ways of proposing knowledge, communicating knowledge, evaluating knowledge and legitimizing knowledge.

Argumentation promotes students' engagement in knowledge construction and evaluation practices, since these processes require the use of criteria for selection and evaluation of evidence, the provision of justifications and the construction of counterarguments (Christodoulou and Osborne, 2014), the use of criteria for distinguishing between good and bad arguments (Zohar and Nemet, 2002) or the evaluation of the arguments constructed by others and the quality of those arguments (Ryu and Sandoval, 2012). Inquiry, on the other hand, promotes the development of skills such as critical thinking, reasoning and habits employed during scientific investigations (Llewellyn, 2013). Marzano (1992) also includes problem-solving, decision-making skills and metacognition as skills that inquiry promotes in students. Scientific practices have a direct link with the study of discourse, according to Kelly and Chen (1999), that used an anthropological approach in science classroom to study how these practices are constructed and acknowledged between the members of a community. Some other studies focused on offering an insight on how scientific discourse is constructed through student small-group interactions (Kelly, Druker and Chen, 1998).

In this study, scientific practices are developed in the context of food safety, regarded as a socio-scientific issue (SSI). SSIs are complex, open-ended, often controversial situations, with no definitive answer (Holbrook and Ranikmae, 2016) that often integrate scientific, technological, and social dimensions (Papadouris, 2012).

The European Commission aims several actions to assure food safety in relation to food, animals and plants. Food policy establishes an array of food safety standards destined to protect and promote the health of the consumer, mentioning the economic, social and often environmental consequences that food production and consumption entails. (Commission of the European Communities, 1999). Notwithstanding, health protection is mentioned as the highest priority issue. Grunert (2005) addresses the relevance of food safety in several areas, such as research, food policy, industry and public debate. Among the variety of factors affecting this relevance, the presence of food scares related to foodborne diseases is said to have brought public attention to food safety issues. Experts in this field consider food safety as everyone's responsibility (Norton and Braden, 2007) so they suggest promoting consumer education. In the Spanish context, this is of relevance, with a recent outbreak of listeriosis caused by manufactured meat, with three people killed and more than 200 people sick. Another well-known case in Spain is the outbreak of bloody diarrhoea caused by E. coli in Germany in May 2011, initially believed to be caused by Spanish products.

However, food safety is not included in any specific block of the secondary education and baccalaureate curriculum in Spain, although considered of great relevance by guidelines from agencies such as WHO, which connects the improvement of competencies in food safety with a decrease in intoxications and to a more targeted and effective response to emergency situations in this area. (FAO/OMS, 2011).

The research goals and questions that guide this investigation are:
RG1. Designing classroom activities aimed at developing scientific practices in the context of food safety for secondary education students.
RQ1. Which features should meet classroom activities for promoting secondary students' engagement in scientific practices in the context of food safety?
RG2. Examining students’ performances in inquiry and argumentation practices.
RQ2a. Which inquiry operations do students perform when solving the tasks? RQ2b. Which sources of information do students use for making a decision during a roleplay game to solve an alimentary emergence?
RQ2c. Which criteria do students consider more important for making a decision during a role-play game to solve an alimentary emergence?
RQ2d. Which difficulties do students face when engaging in inquiry and argumentation practices in the context of food safety?
RG3. Analysing the epistemic knowledge involved in the adequate development of students’ inquiry and argumentation practices.
RQ3a. Which epistemic operations are performed by small groups of students during their conversations about solving an alimentary emergence during a role-play game?
RQ3b Which epistemic operations prevail in students’ decisions for solving an alimentary emergence during a role-play game?
RQ3c Which epistemic aspects students take into account for the design of investigations?

Research design

In terms of methodology, this project is set in qualitative research (Denzin and Lincoln, 2000), and uses strategies from this methodology such as discourse analysis (Gee and Handford, 2012). The intervention designed is framed in food safety, namely in foodborne diseases. Two pilot studies were carried out before the final study to test the sequence of activities. The need to increase the number of participants with a larger base in the field of sciences motivated a change of the subject in which the activities were being implemented. Table 1 summarizes the three studies mentioned above, including an overview of the tasks conducted in each one of them.

Table 1: Summary of pilots and final studies carried out during this project

	Pilot Study 1 (February 2018)	**Pilot Study 2 (June 2018)**	**Final Study (February 2019)**
Schools and classrooms	1 school, 2 classrooms	1 school, 2 classrooms	1 school, 2 classrooms
Subjects, grades and participants	Applied science for professional activity (10th grade, 9 students) Scientific Culture (11th grade, 7 students)	Applied science for professional activity (10th grade, 9 students) Scientific Culture (11th grade, 8 students)	Biology (10th grade, 13 students) (11th grade, 14 students)
Tasks and sessions	4 tasks, 2 sessions	4 tasks, 4 sessions	3 tasks, 4 sessions

Tasks (T) overview	T1: reading and analysing a press report about food poisoning in a school T2: analysis on safety measures implemented in the previous case T3: constructing the WHO protocol for infectious outbreaks T4: analysing the efficiency of the WHO protocol during a real case	T1: introducing the concept of food safety and pooling associated concepts T2: constructing the WHO protocol for infectious outbreaks T3: evaluating and comparing the WHO protocol constructed in the previous task T4: decisionmaking during a role-play game about a disease outbreak	T1: introducing the concept of food safety, analysing population profiles and debating scientific advances T2: designing an experiment to determine the cause of a real disease outbreak T3: decisionmaking during a role-play game about a disease outbreak

Data collection and analysis

Data collection includes audio and video taping of the lessons, as well as the researcher field notes. Students worked divided in small groups. Audio taping of the lessons was later transcribed.

In this proposal, we focus on the analysis of the role-play game in 11th grade lessons. The two sessions were coded and examined using discourse analysis methods. According to Yin (2018), the unit of analysis can be selected depending on the type of analysis performed. Teacher's and students' utterances were unfolded by turns of speech and episodes were identified, grouping together sets of turns in which students focus on a particular decision. In this case, we present an analysis which unit is the turn of speech.

A rubric was designed to identify students' epistemic practices during their conversations in the form of epistemic operations. Epistemic operations can be associated to a specific utterance, a set of utterances or even part of an utterance. Before carrying out the analysis of the final study, some approximations to the final coding system were made using data from the second pilot study with an external expert on the field. For categorizing epistemic operations, the rubric draws from Kelly and Licona’s (2018), Christodoulou and Osborne (2014), Jiménez-Aleixandre et al.'s (2008) and Crujeiras (2014) studies, which are summarized in table 2. Codification was conducted until achieving total coincidence with the supervisor.

Table 2: Coding scheme for the analysis of epistemic operations

EPISTEMIC PRACTICE	EPISTEMIC OPERATION
Proposing Knowledge	- Inferring the scope of a decision - Inferring a plausible cause - Making sense of data - Proposing explanations
Evaluating Knowledge	- Appealing to consistency with previous knowledge - Contrasting claims with available evidence - Acknowledging the absence of data
Communicating Knowledge	- Persuading other members
Legitimizing Knowledge	- Building consensus - Recognizing value of other positions

Results

In this proposal we address the preliminary findings corresponding to students' performances in the role play. The analysis was carried out in order to meet the following goals:

1) To analyse which epistemic operations are performed by the small groups of students in the role play during their conversations about how to proceed for solving the alimentary emergence.

2) To examine the epistemic operations that prevail in students’ decisions for solving the alimentary emergence.

In the case of small groups (districts) discussions, the number of epistemic operations corresponding to each epistemic practice (proposing, evaluating, communicating and legitimizing knowledge) is examined to establish which practice or practices are more common during students' performance. In table 3 the results for 11th grade students are summarised.

Table 3: Epistemic operations performed by 11th grade students during small discussions *Legend: PK: Proposing knowledge, EK: evaluating knowledge; LK: legitimizing knowledge; R1, R2 and R3: Round 1, 2, and 3 respectively*.

	Epistemic Operation	**District 1**			**District 2**			**District 3**			**Total**
		R1	**R2**	**R3**	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**	
PK	Inferring the scope of a decision	8	5	-	1	3	2	1	5	3	28
	Inferring a plausible cause	5	4	4	7	6	7	3	8	9	53
	Proposing explanation	-	7	3	9	4	1	6	10	8	48
	Making sense of data	4	5	1	7	-	1	2	3	1	24
	N	**17**	**21**	**8**	**24**	**13**	**11**	**12**	**26**	**21**	**153**
EK	Appealing to consistency with previous knowledge	2	2	-	2	-	-	2	1	3	12
	Contrasting claims with available evidence	2	2	-	1	-	1	3	1	1	11
	Acknowledging absence of data	1	-	-	-	-	-	-	1	-	2
	N	**5**	**4**	**0**	**3**	**0**	**1**	**5**	**3**	**4**	**25**
CK	Persuading other members	-	1	-	-	-	-	-	1	-	2
	N	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**2**
LK	Building consensus	1	-	-	-	1	-	-	-	-	2
	N	**1**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**2**
N_T		**23**	**26**	**8**	**27**	**14**	**12**	**17**	**30**	**25**	**182**

For the general debate, the type and number of epistemic operations that contribute to the final agreement is examined. In order to do that, interventions made by students were classified depending on whether they supported or rebutted the activation or deactivation of different resources. In figure 1, the final round of the debate, where students discussed the deactivation of food industry versus petrochemical industry is summarised. The final agreement reached after the debate is the deactivation of food industry.

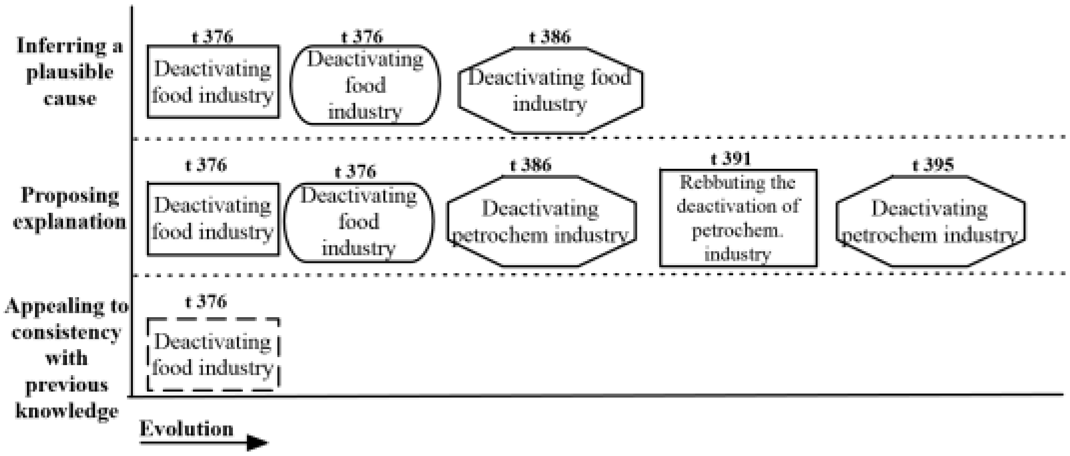

Figure 1: evolution of the general debate in 11th grade during the third and last round

Legend: ▢ operations performed by district 1, ⬡: operations performed by district 2, ▭: operations performed by district 3, —: proposing knowledge, – – : evaluating knowledge.

Preliminary conclusions

Analysing the number of epistemic operations belonging to each epistemic practice for small group discussions, a clear predominance of proposing knowledge operations was found. Epistemic operations of evaluating knowledge were notoriously less frequent while operations belonging to communicating and legitimizing knowledge were anecdotal or even non-existent.

In the case of the general debates, there is a greater presence of epistemic operations relating to evaluating knowledge in decisions with a clear disagreement between the resources to activate and deactivate.

Acknowledgments

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Science practical work: exploring the interplay between teachers' beliefs and practice

Lucy Wood

Abstract

Practical work is a distinctive aspect in science education. In the UK, most science teachers consider it an integral part of their classroom practice. However pedagogical approaches used to orchestrate practical activities vary, with concern being raised about the effectiveness of practical work in developing pupils' conceptual and procedural understanding. This study explores how teachers in England view the purpose and usefulness of practical work as part of science learning for 11-14 year olds. By using the lenses of teachers' pedagogical and selfefficacy beliefs, it seeks to extend our current understanding of how teachers come to their pedagogical decisions relating to practical science. My research design adopts a broadly interpretivist approach using the combination of a questionnaire, semi-structured interviews and lesson observations. The anticipated outcomes may provide a useful framework for supporting teachers' professional development though a greater understanding of the interplay between teachers' pedagogical beliefs, their self-efficacy judgements and their practicaloriented pedagogical decisions.

Key Words

teachers' self-efficacy; teachers' pedagogical beliefs; practical work

Synopsis

Background and rationale

Practical work has been a long-standing feature in science education in the UK with science teachers viewing it as an integral part of their practice (Donnelly, 1998). The purposes of practical work include: (1) improving theoretical understanding; (2) teaching the principles of scientific inquiry; (3) teaching specific practical skills; (4) motivating and engaging pupils; (5) developing higher level skills and attributes (The Gatsby Foundation, 2017).

The value of practical work in establishing the principles of inquiry and teaching specific practical skills is well recognised (Abrahams and Reiss, 2012) but the benefits of an inquiryled teaching approach in supporting pupils' understanding of scientific concepts is more contested. While some studies have shown the positive influence of practical work in revealing or confirming theory (Freedman, 1997, Moeed, 2011), other studies have shown no effect (Abrahams and Millar, 2008, Pine et al., 2006).

Against this complex background, the recent changes to GCSE science specifications in England have resulted in the exclusion of direct practical assessment, with assessment performed through written responses to examination questions. In response to the changes, the publication of ‘Good Practical Science’ (The Gatsby Foundation, 2017) sets out ten ‘benchmark’ recommendations on the measures which needed to be taken by schools The report concluded that most schools currently fall short of the benchmark of varied and frequent practical work in at least half of lessons. My study is therefore timely, as it sets out to indicate how new approaches to assessment of practical science at GCSE may be shaping the composition, emphasis and delivery of the KS3 curriculum.

Teachers’ beliefs and teachers’ self-efficacy

Taking a psychological approach, I am exploring the interplay between teachers’ pedagogical beliefs, teachers’ self-efficacy judgements and the choices they make in the use of practical work for teaching Key Stage 3 (11-14 years) science. By using these two lenses, my study seeks to extend our understanding of the interrelationship between beliefs and self-efficacy when teachers make practical-oriented pedagogical decisions. It builds on my masters’ level research on primary level teachers’ self-efficacy in teaching and assessing science (Wood, 2017).

Teachers’ beliefs about science teaching and learning have been described in various ways. The more traditional stance of a transmission or didactic style of pedagogy has been contrasted with a ‘constructivist’ pedagogy where the teacher facilitates knowledge construction by pupils (Bell and Gilbert, 1996). An alternative description identifies four orientations to teaching science as ‘discovery learning’, ‘processes and scientific method’, ‘didactic and content mastery’ and ‘conceptual change’ (Smith and Neale, 1989) which suggests a more multifaceted pattern of beliefs. In addition, a teacher’s pedagogical beliefs may or may not align with their epistemological beliefs about the nature of science (Trumbull et al., 2006, Lederman, 1999).

The relationship between beliefs and practice is complex; a teacher’s classroom practice will not necessarily reflect their espoused beliefs and the school context may influence how teachers act (Savasci and Berlin, 2012, Mansour, 2013). Some studies have found congruence between teachers’ beliefs about the nature of scientific inquiry and their choice of an inquiryled approach to practical work (Brickhouse, 1990, Crawford, 2007); other studies have highlighted a divergence between a teacher’s beliefs and their practice (Bencze et al., 2006, Bjønness and Knain, 2018). In this study, I focus on teachers’ beliefs relevant to science practical work: their beliefs about (a) the purpose of practical work; (b) the pedagogical approaches to practical work; and (c) how students learn through practical work.

Self-efficacy is concerned with how a person judges their capabilities and the way this judgement may influence both motivation and behaviour (Bandura, 1986). Self-efficacy is a domain- and task-specific; a teacher's self-efficacy [relevant to practical work] includes judgements about their capabilities in classroom management, instructional strategies and student engagement (Tschannen-Moran and Hoy, 2001).

Research has shown that teachers with high self-efficacy are more willing to try out innovative teaching methods (Tschannen-Moran et al., 1998), adopt higher levels of activity based instruction (Enochs et al., 1995) and allow greater student autonomy (Woolfolk et al., 1990). However, Wheatley (2005) contends that lowered self-efficacy can also have value when it leads teachers to a more profound self-evaluation and a desire to improve practice. Conversely, high self-efficacy linked to traditional teaching methods can limit the desire to implement more pupil-centred instruction (Wheatley, 2005). My study explores Wheatley's findings within the dimension of practical work.

Research questions

- What are teachers' beliefs about: (a) the value and purpose of practical work; (b) the pedagogical approaches to practical work; and (c) how students learn?

- How do teachers judge their self-efficacy in relation to practical work, including the domains of classroom management, instructional strategies and student engagement? What is the interplay between a teacher's espoused beliefs, their self-efficacy judgements and their decision making about the use of practical work in the classroom?

Methodology, research design and methods

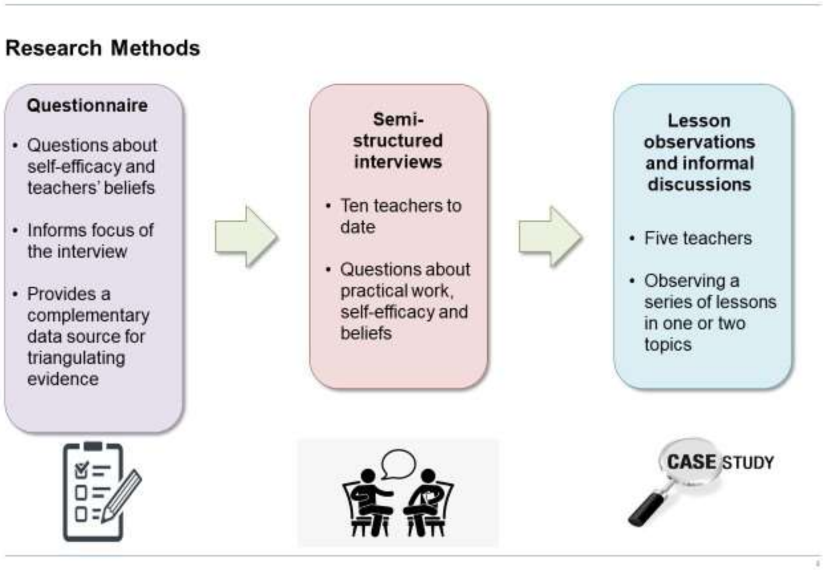
Methodology

The study is concerned with the entity of the science classroom and the phenomenon of science practical activities taking place within it, but it is conceptually focused on the social psychological 'realities' of teachers' beliefs and teachers' self-efficacy as a means of appraising and interpreting the values and intentions of the teachers; it is concerned with how a teacher interprets his or her experience in the classroom and beyond in forming those beliefs. Each teacher has different experiences and these experiences can vary from one lesson to the next. It follows that knowledge about a teacher's beliefs can only be constructed by that teacher; a researcher needs to participate in the research process with the teacher and the knowledge derived must reflect the teacher's own reality (Lincoln et al., 2011). Blaikie describes this position as embracing an 'idealist' ontology, where "reality in what human beings make or construct…it is the meanings and interpretations created and maintained by social actors that constitute social reality for them" (Blaikie, 2007 p.17). Charmaz (2014) also describes it as a 'relativist' ontology where social reality is a process-driven construction which can take multiple forms (Charmaz, 2014).

Closely associated with an idealist or relativist ontology is the epistemology of social constructivism (Lincoln et al., 2011) where knowledge is thought to be derived from social actors making sense of their lived-in world; a profile of each participant's self-efficacy and beliefs is being derived through iterative interactions between the researcher and participants, including interviews and observations.

Research design and research methods

There are four phases to the project: I collaborated with practicing teachers during in the planning and pilot phase (Phase 1). Data collection for the main study (Phase 2 and Phase 3) is spanning a 12-month period from June 2019 to June 2020: Phase 2 has included questionnaires and semi-structured interviews to provide an understanding of teachers' beliefs and selfefficacy through self-reported data; Phase 3 is an in-depth study of teachers' practices, using ethnographic-informed methods to provide a degree of flexibility in keeping with an interpretivist approach (Cohen et al., 2017). The final phase of the project will include data analysis and writing up.



Research Methods

Questionnaire
- Questions about self-efficacy and teachers' beliefs
- Informs focus of the interview
- Provides a complementary data source for triangulating evidence

Semi-structured interviews
- Ten teachers to date
- Questions about practical work, self-efficacy and beliefs

Lesson observations and informal discussions
- Five teachers
- Observing a series of lessons in one or two topics

Questionnaire

The purpose of the questionnaire is threefold: (1) it introduces the participant teacher to the theoretical constructs of teachers' self-efficacy and teachers' pedagogical beliefs; (2) the responses inform the focus of the semi-structured interview; (3) the data will provide a complementary source for comparing evidence derived through the interviews and observations.

The questionnaire is a 'composite instrument' which has drawn on self-efficacy items from the TSES 'Teacher sense of efficacy scale' (Tschannen-Moran and Hoy, 2001) and belief items from the BARSTL 'Beliefs about reformed science teaching and learning' (Sampson et al., 2013).

Sample questions on selfefficacy (six-point scale: nothing → a great deal)	• How much can you do to help pupils work collaboratively? • How much can you do to control disruptive behaviour in the classroom? • How much can you do to motivate pupils who show low interest in schoolwork?
Sample statements on pedagogical beliefs (six- point scale: strongly disagree → strongly agree)	• Pupils create and develop their own knowledge by modifying their existing ideas in an effort to make sense of new and past experiences. • Experiments and investigations should be included in lessons as a way to reinforce scientific concepts pupils have already learned in class.

Semi-structured interviews

Consistent with a social constructivist epistemology, the interviews intend to elicit teachers' own interpretations of the 'science classroom' and of their espoused beliefs (Charmaz, 2014).

A semi-structured protocol was drafted by drawing on existing research on teachers' selfefficacy and beliefs (Lederman et al., 2002, Luft and Roehrig, 2007, Glackin, 2016). However, each individual interview has also be informed by the responses each teacher made to the questionnaire, with the aim of drawing out themes of specific concern or interest to that teacher.

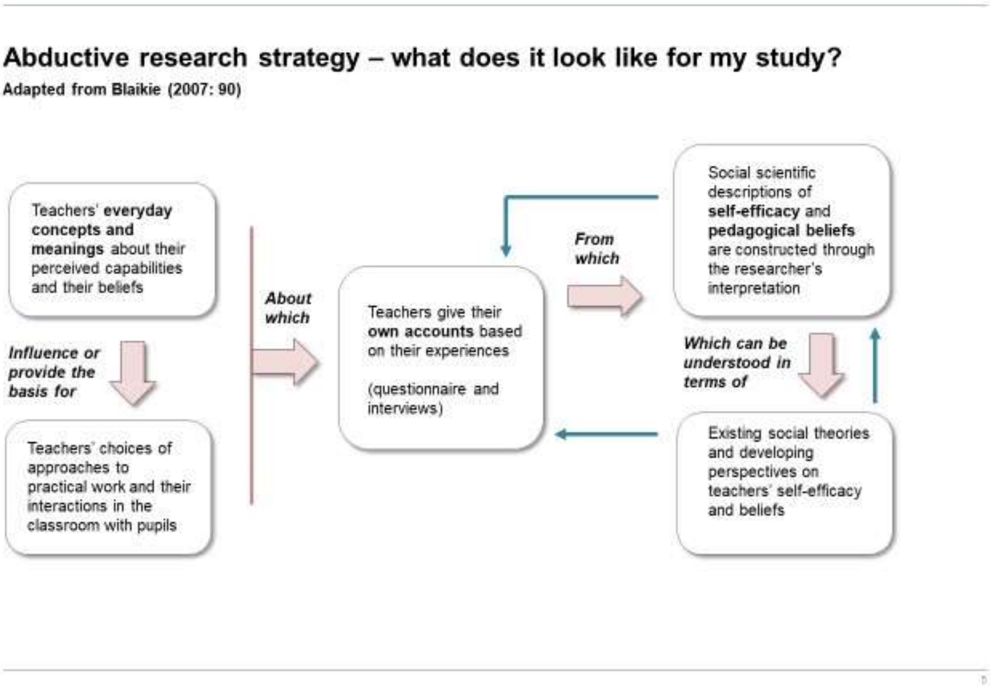
Sample interview questions	• What are the important purposes of practical work? • In your view, how should lessons be structured when using practical activities at Key Stage 3? • In your view, how do pupils learn? • How would you describe/judge your capabilities in teaching science through practical work?

Lesson observations

The schedule of lesson observations will be negotiated with each teacher and adjusted in an ethnographic-informed approach, to allow for some flexibility as the lesson observations progress (Cohen et al., 2017). In broad terms, each teacher will be followed over the course of two science 'topics' with one Year 7 or Year 8 class.

Data collected and preliminary analysis

Data collection commenced in June 2019. To date (February 2020), 20 teachers have completed the questionnaire and 10 teachers have been interviewed. My preliminary analysis has taken an inductive approach to develop initial descriptive codes from the interview data. I have then made abductive comparisons between the data and existing literature on teachers' beliefs and self-efficacy (Blaikie, 2007), as illustrated below.



Abductive research strategy – what does it look like for my study?

Adapted from Blaikie (2007: 90)

Lesson observations have been conducted with two teachers. Each lesson has been audiorecorded and transcribed in full, in addition to recording field notes and collecting sample worksheets. Further observations are planned. The analysis will seek to identify both congruent and divergent classroom practice in relation to the teacher's pedagogical beliefs. I intend to use a multiple case study approach to report my findings.

The study aims to reveal the value of understanding the ways in which individual teachers consider and evaluate their sense of self-efficacy alongside their pedagogical beliefs when making choices for using practical work in the classroom. Professional development which supports teachers in explicitly considering their beliefs associated with practical work and attends to helping teachers building a secure sense of self-efficacy may lead to students experiencing richer opportunities in purposeful practice activities as part of their science learning.

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Formative assessment in chemistry education

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Abstract

According to the many reports done by researchers, summative assessment dominates over formative assessment (FA) in school practice. On the other hand, many pieces of research emphasize the importance of assessment performed in a formative way. This Ph.D. study is aimed to discover whether FA can influence students´ learning outcomes in chemistry lessons. Implementation of FA is done by Formative Assessment Classroom Techniques (FACTs). They are implemented into chemistry lessons. Two groups, control and experimental, are compared by the post-test. Preliminary results show statistically significant differences between these groups. After the lessons, students were asked about their attitudes towards the introduction of FA. In the next steps, the preliminary results will be compared with similar researches. Also, the previous study will be repeated with identified improvements to confirm preliminary results. Teachers´ attitudes toward this assessment will be observed to identify their influence on students´ perceptions of FA.

Introduction

Assessment plays a fundamental role in the educational system (Black, 1993). These days, two basic types of assessment are distinguished: summative assessment and formative assessment. Summative assessment is mostly based on score or tests and is applied at the end of some period of the educational process to summarize the evidence of learning progression (Harlen, 2000). On the other hand, formative assessment is used during the educational process and provides extended feedback (Scriven, 1967). Many types of research were done about formative assessment and it was agreed that it should help all who are involved – teachers, students, and curriculum makers (Black & Wiliam, 1998; Bloom, Hastings, & Madaus, 1971; Sadler, 1989; Topping, 1998). In the last years, the biggest influence on formative assessment has the work of Black and Wiliam (1998) “Inside the Black Box” in which authors presented more than 250 studies about assessment in the classroom. Their work has started a revolution in assessment and many projects and researches follow it (Black, Harrison, Lee, Marshall, & Wiliam, 2003, 2004; Cohen & Lotan, 2014). Afterward in Keeping Learning on Track® Program, Wiliam (2007) and Educational Testing Service developed five key strategies of formative assessment: sharing learning expectations, questioning, feedback, selfassessment, and peer assessment (Bennett, 2011). ‘Formative Assessment Classroom Techniques’ (FACTs) are the type of these key strategies (Keeley, 2008). FACTs are short activities, which are mostly done by students at the beginning of the lesson, during the lesson or in the end of the lesson. Well known examples of these FACTs are true or false statements, vocabulary square, checklist, K-W-L, concept map, and exit card (Srivastava, Mishra, & Waghmare, 2018; Zhao, Van den Heuvel-Panhuizen, & Veldhuis, 2016).

True or false statements – this is a tool in which student must decide whether the statement about the topic is or is not true. He/she decides about the verity of them at the beginning of the lesson and at the end of the lesson (Hubbard, Potts, & Couch, 2017).

K-W-L chart – it is a three steps procedure: At the beginning of the lesson, a student writes what he/she knows about the topic (*K*) and what he/she wants to know (*W to know*). At the end of the lesson, the student writes what he has learned (*L*) (Ogle, 1986).

Vocabulary square – this tool is a square divided into four parts. In which part one of the followed topics is described: definition, facts or characteristics, examples, nonexamples (Frayer, Fredrick, & Klausmeier, 1969).

Exit card – sometimes called minute paper or 3-2-1 card is a tool, in which where the student writes 3 facts from that day´s lesson, 2 facts which he/she considers as an interesting and 1 question that he/she can have about the topic (Wilson, 1986).

Checklist – the main goal of this tool is to identify which task from the lessons was not completed, and a scale (5, 3, or 2-points) is used for the identification (Ma et al., 2012).
Mind map – this is a diagram which helps the student to organize and visualize their knowledge. Students write terms and networks between them (Champagne, Klopfer, Desena, & Squires, 1981).

It is vital to understand students´ perceptions and attitudes towards assessment in general (Bader, Burner, Hoem Iversen, & Varga, 2019). When students have a positive perception of something, it helps and motivates them to learn (Weurlander, Söderberg, Scheja, Hult, & Wernerson, 2012).

Research questions

So far, two research questions were given and preliminarily studied:

1. Does the introduction of formative assessment based on FACTs influence students´ learning outcomes?
2. What are students' attitudes towards learning with FACTs?

Research questions for the next study:

1. What are teachers´ attitudes towards learning with FACTs?
2. Can teachers´ attitudes towards learning with FACTs influence students´ attitudes towards learning with FACTs?

Methodology

To get the answers to the research questions, 10 lessons with FACTs were created. The topic “Mixtures” was chosen because this topic is one of the first which is taught during chemistry lessons.

At the first stage, teachers who could perform the lessons are chosen. All teachers must have participated in the same course about formative assessment and thus they have a similar background about this topic. Each teacher teaches one experimental group (class) and one control group (class).

At the beginning of the research, a pre-test is given to the students to determine and compare their entry level of knowledge about the previous topic in chemistry lessons. Accordingly, classes are assigned to the control or experimental group. After the pretest is written, 10 lessons on the topic “Mixtures” are taught. The experimental group is taught with FACTs (Table 1), lessons in the control group are run without FACTs.

Table 1 Type of the FACT used in the lesson.

Number of a lesson	Type of FACT
1	True or false statements
2	Vocabulary square, checklist
3	K-W-L
4	True or false statements
5	K-W-L
6	Checklist
7	Concept map
8	Exit card
9	True or false statements
10	Checklist

After the 10 lessons, the post-test is written by all students. Both tests consisted of 10 items build in different domains of Bloom´s revised taxonomy (remember, understand, apply, analyze) as is described in Table 2. Items in both tests were created and evaluated by the National Institute for Certified Educational Measurements of Ministry of Education, Science, Research and Sport of Slovak Republic. The tests were created with the cooperation of the teachers participating in the research. There was 1 point awarded for each correct answer and 0 points for an incorrect one, therefore the maximum score was 10 points. To discover the reliability of the test, Cronbach´s alpha was calculated
(α=.693).

Table 2 Assignment of the post-test items to Bloom's learning domains.

Number of an item	Learning domains for the post-test	Type of question
1	Understand (procedural knowledge)	single select multiple choice
2	Analyse (conceptual knowledge)	single select multiple choice
3	Analyse (procedural knowledge)	single select multiple choice
4	Understand (conceptual knowledge)	rank order
5	Understand (conceptual knowledge)	open-ended
6	Apply (procedural knowledge)	open-ended
7	Apply (factual knowledge)	single select multiple choice
8	Remember (conceptual knowledge)	semantic differential scale
9	Remember (factual knowledge)	single select multiple choice
10	Analyse (procedural knowledge)	single select multiple choice

Afterward, a questionnaire with 4 questions is given to the students in the experimental group to identify their attitudes towards the lessons with FACTs. Students chose from 4-point Likert scale with answers: "I disagree strongly", "I disagree", "I agree", "I agree strongly" to each of the followed statements:

1. I liked it when the teacher assessed me this way, not only by a grade.
2. This assessment helped me to realize where I have my shortcomings.
3. I think this assessment could help me with my school results.
4. It was fun when I used this kind of assessment.

The answers were scaled from 1 for the answer “I disagree strongly” to 4 for the answer “I agree strongly”. Also, Cronbach´s alpha was calculated for the questionnaire (α=.740).

Preliminary results and discussion

In the academic year 2018/2019, the first round of the research was run. Five teachers were engaged in the research and they taught 202 students in total. There were 105 (52%) students in the experimental group and 97 (48%) students in the control group.

They were students of the 7th grade of secondary school and they were 12-13 years old.

The post-test score of the experimental and control group was evaluated.

KolmogorovSmirnov normality test was used to control normal distribution for the total score (*p*<,001) therefore non-parametrical tests were used for further analysis.

To compare those two groups, the chi-squared test was used. The results are presented in Table 3. The score of the experimental and control group was compared. The items were analyzed not only separately, but also as a group of items categorized by the same learning domain of Blooms´ revised taxonomy and as the entire test.

Table 3 Post-test results analyzed by chi-squared test

Items	**Control group score [no. of points]**		**Experimental group score [no. of points]**		**Pearson chi-squared**	**df**	**Asymp. Sig.**
	Mean	**Median**	**Mean**	**Median**			
entire test	3.2	3.0	5.3	5.0	51.706	9	<.001
Items grouped	.58	.00	1.01	1.00			
	1.77	2.00	2.23	2.00			
	.28	.00	.77	1.00			
	.58	.00	1.29	1.00			
remember					19.111	2	<.001
understand					17.471	3	.001
apply					28.603	2	<.001
analyse					34.015	3	<.001

Items separated	1	.31	.00	.56	1.00	13.056	1	<.001
	2	.19	.00	.53	1.00	26.269	1	<.001
	3	.29	.00	.70	1.00	34.923	1	<.001
	4	.66	1.00	.80	1.00	5.060	1	.024
	5	.80	1.00	.87	1.00	1.443	1	.230
	6	.20	.00	.48	.00	17.616	1	<.001
	7	.08	.00	.30	.00	14.651	1	<.001
	8	.43	.00	.42	.00	.040	1	.841
	9	.14	.00	.59	1.00	42.764	1	<.001
	10	.10	.00	.05	.00	2.257	1	.133

The score of the experimental group is higher than that of the control group for the entire test. The difference is statistically significant (*p*<.0001). That means, that group taught with FACTs performs better. Similar results are obtained in grouped items where the experimental group achieved statistically higher scores in all four analyzed domains: remember, understand, apply, analyze.

Answers in the questionnaire were analyzed and mean, median, and standard deviations were calculated. The results are presented in Figure 1.

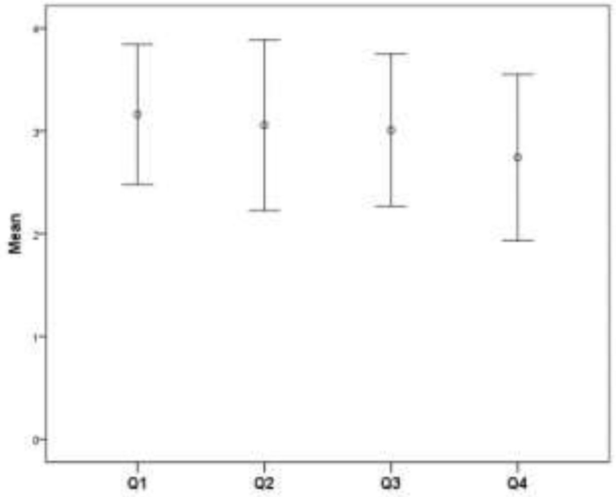

Figure 1. Mean and standard deviation of answers to the questionnaire. Q1: I liked it when the teacher at first assessed me this way, not only by a grade. Q2: This assessment helped me to realize where I have my shortcomings. Q3: I think this assessment could help me with my school results. Q4: It was fun when I used this kind of assessment.

Analysis of the answers in the questionnaire shows, that students have positive perceptions of this form of assessment and they found it useful being assessed in this way before a test.

Conclusion

As the results suggest, using FACTs during chemistry lessons has a positive impact on students´ learning outcomes measured by the post-test. The results were emphasized by statistical analysis of the total score of control and experimental group, where statistically significant differences were observed ($p<.05$). These results need to be discussed and compared with other literature resources. Students´ attitudes were also obtained. Positive reactions towards the implementation of FACTs were observed. These can encourage teachers to use the FACTs in their daily practice. In the next phases, research will be repeated and teachers´ attitudes will be observed.

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Analysis of chemistry teacher students' success and failure in solving multicomponent tasks with problematic elements

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Abstract

Students' ability to solve problem tasks is seen by the OECD as key aspect of education. Research results (e.g. PISA) indicate significant reserves of Czech pupils in this area. The possible cause is the lack of development of these abilities in schools. The active role of the teacher is crucial. Nevertheless, teachers' ability to solve problem tasks has not yet been examined. The presented research focuses on pre-service chemistry teachers, the condition and possibilities of development of their ability to solve problem tasks. The aim is to map their adopted practices, strategies and bottlenecks of task-solving process. Multicomponent tasks for lower-secondary school student assessment and the released items from PISA were used. To get more detailed information, retrospective think-aloud together with eye-tracking were used. The results suggest that pre-service chemistry teachers (N=33) have more difficulty solving tasks set in a chemical context than solving general science problems.

The main text

This research is aimed at identifying the ability of pre-service chemistry teachers to address problem tasks as one of the key components of science education. The main goal of the study is to identify the strategies and critical points of them solving the tasks. Research focuses not only on solving problems in a chemistry context, but also general science tasks.

Literature review

PISA

In international comparison, Czech students are average in their skills to solve problem tasks (e.g. OECD, 2018). However, the results of the PISA remain relatively detached from specific ideas for the improvement of the education systems. The reasons for students’ failures (tasks, concepts or operations that have caused problems) remain unclear. The solution of this are both secondary analysis of data from the PISA survey and further study of the behaviour of the tasks used in the surveys.

Problem-solving in the field of chemistry education

Problem-solving belongs to the key competences in the Czech curriculum (FEP, 2017) and is also one of the 21st century skills (see Bellanca 2010). Research (Surif, Ibrahim, & Dalim 2014) indicates low students’ ability to solve chemistry problems. The qualitative research offers a deeper understanding in this respect. There are typical strategies and steps solvers use while solving-problems. These were analysed e.g. by Gabel, Sherwood and Enochs (1984) or Koreneková (2018) using the think-aloud method in both cases.

The use of eye-tracking in science-oriented didactic research

There are some limitations of using think-aloud method such as difficulty of thinking and talking at once (Ericsson & Simon, 1980) or inaccuracy of information (Cooke & Cuddihy, 2005). The use of an eye-camera in combination with this method offer promising results in clarifying pre-service teachers' results.

Research focused on monitoring the solution procedure of PISA in reading literacy was carried out by Krstić, Šoškić, Ković, and Holmqvist (2018), who used eye-tracking to examine the fluency of reading and information that individual groups of readers focus on. The results show that good investigators use one similar procedure, whereas unsuccessful solvers use more variable strategies. Successful solvers also, unlike the unsuccessful ones, also focus on key information after reading the whole text. The eye camera seems useful for analysing the problem-solving process as it provides information about strategies students use when solving the tasks. For example, Hegarty (1992) investigated, if a task was solved as whole or if the solvers broke it down into parts. Khooshabeh, Hegarty, and Shipley (2013) found out that successful solvers adjust their strategies based on a task type, unsuccessful solvers apply strategies regardless of the task.

Studies on chemistry (Hinze, Rapp, Williamson, Shultz, Deslongchamps, and Williamson, 2013) show similar results in the preference of molecule type models according to the type of task among successful solvers.

Another complex research method in this field was used by Tsai, Hou, Lai, Liu, a Yang (2012). In their research, university students solved a multiple-choice task. The results show that successful solvers focused on relevant factors of the task instruction. A mixed study by Hansen (2014) used multimodal data (eye-tracking, think-aloud, score, sketches), focused on students' work with different visual representations.

In Czech education research, attention was paid to strategies for solving tasks mainly in physical education (see Hejnová & Kekule, 2018; Kekule & Viiri, 2018). Tóthová (2019) and Rusek, Koreneková and Tóthová (2019) used the method in chemistry education research. The results of the research show that students often fail in solving multicomponent science tasks despite the original test results may, at first sight, seem to show positive results.

Blank places in the field

The presented research responds to the need to develop students' problem-solving skills. They should be developed by teachers in schools. However, if a teacher is to develop these students' skills, they must possess skills developed themselves (Krulik & Rudnick, 1982). Although there has been research focusing on partial knowledge and strategies, the specific procedure and problems encountered by pre-service or in-service teachers regarding problem tasks have not been mapped yet. Barba and Rubba (1992) focused on the ratio of content knowledge and problem-solving skills using quantitative research (testing). Gabel, Sherwood and Enochs (1984) used think-aloud to investigate strategies high school students used while solving chemistry problem-tasks. However, the use of modern methods allows to identify more accurate procedures, strategies and problems. This knowledge can lead to improvement and better preparation of teacher students training. So far, such research is missing in scholarly literature.

Research questions

The main objective of this research is concretized by the following research questions:
What are the strategies used by chemistry teacher students to solve chemistry tasks compared to tasks focused on measuring scientific literacy?
What are the similarities and differences in the process of problem-solving between successful and unsuccessful task solvers?
What are the similarities and differences in the problem-solving process between solvers in different degrees of education?
What stages of the problem-solving process are critical for chemistry pre-service teachers?

Methodology

This research is planned in two phases. The first consists of testing pre-service chemistry teachers' skills to solve multicomponent tasks. Based on the results, respondents will be selected for the second phase of the project. In this phase, they will address analogous tasks and their progress will be analysed in more detail. The solution procedure will be analysed in line with the objectives of the project for both: tasks focused primarily on chemical content and tasks accentuating a wider level of scientific literacy (see e.g. OECD 2019).

The research sample will be composed of students at the Department of Chemistry and Chemistry Education, Faculty of Education, Charles University. From the total number of students in the first year of bachelor's study program 2019/2020 (N=33) and the last year of master's degree (N=12). Successful (N=2), average (N=2) and unsuccessful (N=2) students will be selected from both of the groups based on a pre-test results for the qualitative study.

Research methods

The research is based on mixed methods (see e.g Hinze et al., 2013). First, quantitative part of research contains tests consisting of validated complex tasks. Second, qualitative part includes the eye-tracking method which is completed with the retrospective thinkaloud (RTA), i.e. a retrospective description of the procedure by the task solver. To reduce the inaccuracies of the provided information, the study participants will be shown the record of their progress. It is precisely the interconnection of these methods that proves to be the most effective and can thus obtain the most information (Hansen, 1991). A structured interview will be held with each participant to add further information.

Data analysis

To answer the quantitative research questions, Areas of Interest (*AoI),* i.e. zones focusing on one topic, (e.g. picture, answer choice, etc.) will be defined. The time fixation duration in the AoI (see e.g. Tsai et al., 2012) will be analysed with the use of statsitical tests (depending on the data) to see differences in pre-service teachers' problem-solving approach.
Qualitative data comprises the think-aloud and interviews which will be transcribed verbatim and coded using the ATLAS.ti software with a special attention to the expansive and limiting strategies (see Oglivie, 2009) and problems.

Results

Research design

I. Processing the systematic research of scholarly literature focused on methods of identifying problem-solving strategies with particular emphasis on the method of eyetracking and retrospective think-aloud including results interpretations.

II. Pre-test Build (6 Tasks)
Pre-test is divided into two parts. It consists of three chemical tasks (Czech Chemistry curriculum tasks), three scientific literacy tasks (PISA tasks).

III. Pre-test: 1st year bachelor students and the 2nd year of follow-up master's degree in Chemistry education. The evaluation uses the model from e.g. PISA. Two points for the correct solution, one point for partially correct solution and no point for incorrect solution. The correctness of the answers was evaluated according to the attached key from both PISA and Czech curriculum task publications.

IV. The selection of respondents to the qualitative phase of the project based on pre-test and the year of studying (12 students).

V. Qualitative study procedure

Students will solve complex tasks (one chemical and one focused on scientific literacy task) on the computer with the movement of their eyes recorded by an eye-tracking device. After solving the tasks, students will be asked to retrospectively describe their problem-solving progress (retrospective think-aloud). The record from the eye-tracker will be shown to them as a support. With the use of subsequent semi-structured interview, more information will be obtained about the strategies and experience of the respondent's tasks solving.

VI. Analysis of respondents' success in solving chemical tasks and science-oriented tasks depending on the information will be performed – analysis of responses, eye-tracking record, retrospective think-aloud and structured conversation.

VII. Repetition of the same procedure for the students in the academic year 2020/2021.

VIII. Data analysis identical to previous one.

IX. Identification of similarities and differences in problem-solving procedures with chemical focus and tasks focused on scientific literacy.

X. Identification of the critical points in solving tasks for pre-service chemistry teachers.

XI. Formulation of possible intervention steps leading to the critical points development.

Collected data

The results so far include testing that took place in two rounds. The first focused on solving chemical problem tasks (from Czech Curriculum), the second on general tasks (from PISA).

Both parts of the testing contained three tasks from different thematic units. These were given to the first-year bachelor students. Both types of tasks are designed for 15-year-olds. Chemistry teacher students achieved relatively low results in chemistry-oriented tasks. 33% of the students achieved less than a quarter of the test success rate. 30% of the students were between 25-49% of the success rate. The same number of students achieved results of 50-74%. Only 6% of the students achieved a 75-100% success rate in the test.
In general, scientific-literacy-focused tasks (PISA), their results were different. A minimum share (7 %) of the students achieved a success rate of less than 25%. In the 2549% success category, 14% of students are in the success category. 46% of students achieved a success rate of 50-74%. 32 % of students ranged in 75-100% success rate.

Discussion

The data so far received in this research can be compared with other results: results from PISA in the scientific literacy test (OECD, 2019), and the results in the chemistry-oriented test (Tóthová, 2019). A possible cause of the students' failure in solving problem tasks is their excretion from the school/laboratory environment (Palečková, Tomášková, & Blažek, 2014). This could also explain the failure of chemistry teacher students (more than half of students have not achieved even a 50% success rate) in solving this type of tasks set in a chemical context. However, this does not explain the higher success rate in science-oriented problem tasks (80% of students achieved 50% or more in the test). More information is therefore needed.

In the PISA tasks, chemistry teacher students (compared to the average results of 15-yearold students) (Tomášek & Potužníková, 2004) have a higher success rate. It seems that the task difficulty (PISA task - Pressure pot), which was the most difficult in the pre-test even for 15-year-olds, was the most difficult also for the chemistry teacher students. Their results in this task are almost identical with those of Czech students in PISA 2003 (deviation 7.3%). In one question, the success rate of university students was below the average of Czech 15-year-old students.

As far as the chemistry-oriented tasks are concerned, the chemistry teacher students were less successful in solving the tasks compared to their overall results in PISA tasks. Compared to the non-chemical secondary (vocational) school students` (15-year-old students) results, the chemistry teacher students' results are better. Yet their success rate is low. 64% of teacher students did not achieve a success rate of 50% in the test. For the secondary school students, this percentage was noticeably higher in the same test (86%). The secondary school students` results can be explained by their attitudes towards chemistry (Rusek, 2014). However, the reason for such a low success rate for teacher students who chose chemistry as one of their majors and their ability to solve problem tasks when they enter work life is unclear. In this respect, further steps are planned for the first half of 2020:

- Qualitative analysis of the task solution procedure for the selected sample of students (eye-tracking, think-aloud, structured interview)
- Pre-test and qualitative analysis (eye-tracking, think-aloud, structured conversation) for students in the final year of their studies (just before they start leave for teaching service).

Preliminary findings

Pilot research was conducted on first-year students of non-chemical vocational school. The results of the research show that the only number of points in test is burdened with false positive results. The used qualitative method proved to be efficient (Tóthová, 2019).

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Science teacher competence in citizenship education for sustainability

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Study outline

Issues related to sustainability have a big impact on our society. This raises the need for citizenship education aiming for informed opinion-forming. Students need to be able to evaluate different perspectives, explore solution strategies, and reflect on the social side of a scientific dilemma (Westheimer, 2008). Even though opinion forming related to Socio-Scientific Issues (SSIs) is a curricular aim of science education globally, many secondary school science teachers feel the need to improve their competence regarding fostering this form of scientific citizenship.

Citizenship is defined by the Dutch *Onderwijsraad* (‘Educational board’, 2003) as the willingness and the ability to take part in a community and actively contribute to this. Fostering democratic citizenship is not restricted to the pedagogical mission of subjects like social studies only. In a science education context this form of citizenship is closely linked to opinion forming on SSIs.

SSIs involve both societal and scientific aspects, concern many different stakeholders, and have a controversial nature, without clear cut answers or solutions (Ratcliffe & Grace, 2003). Controversy can be related to risk perception, interpretation of data and theories, and the social impact of science and technology (Levinson, 2006). SSIs related to sustainability generally include people, planet and prosperity aspects (Hammond, 2006). Students need future thinking competencies, normative competencies and systems thinking competencies, among others, to successfully reason about sustainability (Wiek, Withycombe & Redman, 2011).

It remains difficult to successfully and effectively integrate citizenship education in the science classroom. Science teachers feel a lack of competence with regard to citizenship education and therefore students lack opportunities to intensely think through their own and their peers’ feelings and opinions about SSIs (Day & Bryce, 2011). Teachers express a need for supportive educational materials, tools, action strategies and assessment options to successfully integrate citizenship education in their science lessons, thus fostering critical citizenship in their students (Tidemand & Nielsen, 2017).

A promising way to promote citizenship is through Socio-Scientific Inquiry-Based Learning (SSIBL; Levinson, 2018), which integrates SSIs and Inquiry-Based Learning with Citizenship Education. Whilst teachers see SSIBL as of added value to their teaching repertoire (Knippels & Van Harskamp, 2018), the approach has not yet been extensively tested in classroom practice. The aim of this study is to strengthen teacher competence regarding citizenship concerning sustainability issues, thus enabling them to promote sustainability citizenship in their students.

Theoretical background

Science teachers experience a lack of competence to effectively incorporate scientific citizenship in their teaching (Tidemand & Nielsen, 2017). They feel more confident to teach content and subject knowledge, so-called ‘hard science’, instead of contested knowledge, the possibility of multiple solutions, and the controversial and ethical side of science (Day & Bryce, 2011). A possible cause is the lack of confidence science teachers experience regarding letting go of control during teaching (Hodson, 2003). Teaching about SSIs necessarily incorporates these uncertainties because of the openended and messy nature of SSIs.

Additionally, science teachers feel insecure in using teaching methods more commonly related to the humanities, such as classroom dialogue. Science teachers are often unsure about their capability to guide a dialogue (Corrigan, Dillon, & Gunstone, 2007). Moreover, some science teachers do not value using a dialogue as a teaching tool in science, since they fear it might be less effective and more time-consuming than regular teaching methods.

Opinion forming through science education has been extensively researched. Science teachers who feel a lack of competence with regard to citizenship education could for instance focus on the emotions of their students regarding an SSI. During opinion forming, opinions are usually based on quick intuition and emotions first, which later are supplemented by moral reasoning to find arguments which support these views (Haidt, 2001). Therefore, it is important to pay attention to affective elements of the opinion forming process.

Research questions

The main aim of the study is stimulating science teacher’s competence in such diverse areas as developing educational materials promoting sustainability citizenship, carrying out scientific citizenship education in the classroom, and assessing learning outcomes to monitor scientific citizenship in their students. The outcome of the project is a set of learning and teaching strategies and tools for supporting teachers and student competence during citizenship education related to sustainability in the science classroom. This will ultimately lead to a more effective integration of citizenship in science education, thus preparing students for active participation in societally relevant scientific decision making.

The main research question is: *How to support development of science teachers' competence in citizenship education on sustainability issues?* Sub questions include *What are current student and teacher views, attitudes and behaviours related to citizenship and sustainability education in The Netherlands?* and *What educational phases strengthen student's sustainability citizenship?*

Methods

Outline

Four studies are carried out to support teacher competence in promoting citizenship related to sustainability issues at lower secondary level. The first study focussed on teachers' and students' views on scientific citizenship and sustainability. The main method for the second, third and fourth study consists of Lesson Study (LS). LS focuses on the learning process of both the students and the teachers.

Year 1 (2019) –The first study consisted of semi-structured, face to face interviews with students and teachers, aimed at measuring views and conceptions of students (n=42) and teachers (n=42). Subjects were selected by sending emails to schools across The Netherlands, keeping in mind a sufficient geological spread and diversity of urban and non-urban schools.

The second study consists of one LS-cycle (Fernandez & Yoshida, 2008). The LS-team consists of six teachers and three researchers who are involved during the whole project. In one LS-cycle the consortium teachers and researchers: a) develop learning goals and pose a research question, b) design the lesson, c) teach and observe, and d) reflect and revise, after which (e) the lessons are given again in a new class.

The focus of this study is measuring the competence and self-efficacy of the teachers regarding citizenship education and sustainability issues, and providing concrete tools and points of interest for the third study. Self-efficacy was measured using the tool developed by Tschannen-Moran & Woolfolk Hoy (2001). Close observation (video recording and field notes) of the LS-cycle complemented with face-to-face interviews with the teachers before and after the cycle, and audio recordings of all lesson design and evaluation sessions with the teachers provided more information on teacher competence.

Additionally, a pre- and post-test questionnaire with 5-point Likert scale questions is in development to measure sustainability thinking and scientific citizenship of students. It was validated through a first round of Principle Factor Analysis (n=769 students). A second round of validation is planned for early 2020, after which it will be used for study three.

Year 2 (2020) – During the third study, consisting of a longitudinal LS of a year, the consortium teachers will design new lessons for different subjects, based on findings from the first two studies. Multiple LS-cycles will be implemented, as described above, in two classes during a whole school year. Next to the teachers' competence and selfefficacy, the focus of this longitudinal study is on students' development of sustainability thinking and scientific citizenship, based on Wiek, Withycombe and Redman's (2011) sustainability thinking competencies. These data provide insight in effective lesson strategies, thus further deepening teacher competence. This study is in progress, with the first cycle having been completed at the time of writing.

During years 3 (2021) and 4 (2022) of the project, the six consortium teachers will implement LS in their own schools, with new LS-teams consisting of interdisciplinary groups of teachers. The aim of this phase is dissemination and gaining further insight in the processes underlying development of sustainability citizenship with new teachers and students. The researchers will follow these LS-cycles from a distance, by collecting teachers' and students' materials.

Data collection

Data for this project will consist of interviews with teachers and students (study 1). During the LS-cycles (studies 2, 3, and 4), data will be collected from many different sources, including student materials, audio- and video recordings of lessons, pre- and post-test data from students, interviews with the teachers before and after the cycles, interviews with selected students, audio recordings of design- and evaluation sessions, and self-efficacy data from the teacher questionnaires.

Collected data and analysis

Interviews – As of now, the first study has been completed. Data consist of 42 student interviews and 42 teacher interviews, all of which have been transcribed verbatim. A first round of data analysis of the student interviews has been performed, and preliminary findings are available. A second rater will go through a sample of the data to calculate interrater reliability. The teacher interviews have yet to be analysed.

Questionnaire development – The pre-post-test questionnaire has gone through a first round of testing with expert consultation, think-aloud interviews with 4 students, a pilot round with two classes and a full test with 769 students completed. Principle Factor Analysis has been performed in IBM SPSS Statistics, after which changes have been made to the questionnaire, with some questions being dropped and some questions being added. A second round of validation has started.

Lesson Study 1 – The first LS-cycle has been carried out with two classes (48 students). Lesson design was based on mining of elements for smartphones, and issues related to this process. Student materials have been analysed. This was done by labelling aspects of sustainability (people, planet and prosperity) that students used in their issue summaries. Additionally, answers to questions in the lesson module have been categorised to show common themes in student reasoning. The pre-post-test was analysed by calculating means for the different factors in the first version of the questionnaire. Analysis of observation forms, post-lesson discussion, student interviews, lesson design and evaluation sessions, and teacher interviews is in progress.

Preliminary findings

Interviews – Dutch students mainly come into contact with sustainability at school (31/42) and at home (28/42), whilst almost none of them report discussing sustainability related topics with their friends (3/42). When asked whether students feel they experience problems related to sustainability in their daily lives, 24/42 answer yes. This forms a stark contrast with 39/42 students thinking sustainability issues are felt elsewhere on the planet. However, we also see that 14/42 students have a very negative image of the future, and that 29 students take sustainability into account during their daily lives. From these data we can conclude that the sampled students think about sustainability and regard it as being an important issue, but that they generally perceive it to be someone else’s problem. These insights provide teachers with a suitable starting point to develop educational materials, thus improving their teaching competence.

Questionnaire development – Principle Component Analysis of the 769 responses to the questionnaire yielded a 10 factor structure. An additional knowledge scale was included in the questionnaire (Table 1). Questions have been added to the factors that contained very few questions and to those with alphas below .60, and some questions that were dropped after Factor Analysis have been adapted. The new version of the questionnaire is currently being tested with a further 800 students.

Table 1. Descriptive statistics for the sustainability citizenship questionnaire, showing reliability, means (one dichotomous, true-false scale; ten 5-point Likert scales), standard deviations and number of questions.

Scales	α	M	SD	N
Sustainability knowledge scale	**.36**	.46	.50	8
Reflection on sustainability	.93	2.29	1.14	11
Skills defending own opinion	.86	4.07	.91	3
Sustainability attitudes	.86	3.31	1.07	9
Sustainability skills	.66	3.22	.98	4
General discussion skills	.81	3.62	.97	6
Complexity of sustainability	.60	3.73	.93	3
General social norms	.82	4.22	.90	4
Friends and sustainability	.86	1.58	.87	2
Sustainability at home	.80	2.13	1.02	2
Causes of sustainability issues	**.35**	3.07	1.01	2

Lesson Study 1 – Students made a summary of their inquiry on issues related to mining of smartphone elements. In these summaries, out of 148 codes given, People (43%) and Planet (36%) aspects were mentioned most often, whereas Prosperity aspects were underrepresented (21%). Open-ended questions in the lesson materials show that students want to solve sustainability issues related to smartphones by promoting recycling (13) and improving working conditions (9). These data again show a bigger emphasis on People and Planet aspects in student reasoning and could be used by teachers to tailor their lessons to better suit their student's needs.

Teacher self-efficacy did not change significantly after LS1 according to the pre-post questionnaire, although in interviews teachers mention seeing more opportunities for citizenship education and feeling they expanded their education toolkit. One teacher comments: '*At first I did not see the point of it* [a dialogue activity]*, but it really worked well for the students*'.

Concluding, these first analyses show that sustainability is something students do think about, but their reasoning is limited to People and Planet aspects most strongly, with Prosperity aspects being less evident. Concerning topic selection, issues from the students' surroundings or living area seem most effective. These data will be enriched with data from the other sources, ultimately leading to a set of teaching and learning strategies that help to promote teachers' competence on sustainability citizenship in science education.

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Patterns of Collaborative Science Learning

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Abstract

This research applies network analysis methods to investigate learning processes to explore intra-action patterns connected to learning outcomes. Network analysis methods are able to separate the role of each individual component of an assemblage with minimal interpretation. The extracted roles are nonrandom triadic patterns that can be determined for even small networks. The research includes three sub-studies. Study 1 developed methods in the context of pre-service teachers' online discussions of the history of physics. In Studies 2 and 3, the methods are applied in digitally intensive project-based learning modules in upper secondary school physics. Study 2 focuses on identifying material-dialogic intra-actions from focus group video data (20 students and 40 hours) and coding them into a network. Study 3 analyses connection of intra-action patterns and learning outcomes. The results will provide information of the role of digital tools in science learning and how to orchestrate students' collaboration.

Keywords: network analysis, material-dialogic, intra-action

My research aims to investigate students' patterns of collaboration by modelling their small group behaviour as networks during practical work, with a focus on digitalized science practices. The network will consist of students, teachers and the material affordances students use during collaboration. By analysing this network, it is possible to study patterns of collaboration and show what role each actor plays in learning process.

Human interactions in collaboration can be considered complex phenomena, especially in real-world settings with material affordances. Network analysis methods allow for the investigation of dynamic systems (Holme & Saramäki, 2012) and complex systems with noisy data (Barabási, 2012). For example, status order in small task groups have been studied using dynamic network models (Skvoretz & Fararo, 1996). Modelling collaboration as a network of connected individuals makes it possible to research learning processes quantitatively with minimal interpretation. The connection between the learning process patterns and learning outcomes can then be investigated.   Investigating collaboration and how each individual component functions as part of the whole requires a method that can distinguish between different possible roles. McDonnell et al. (2014) have presented a method to compute network roles based on triadic patterns (i.e. network motifs consisting of only three nodes). The motifs are defined as directed sub-graphs that occur more often in natural networks than in a purely random network. Directed networks have 30 different types of motif-roles in 13 different motifs, and they are grouped into nine different roles. These roles are sink, source, relay, reciprocal and various combinations. The roles can be structural or functional. Structural roles are the building blocks of the network, and functional roles are all possible patterns for edges in the network. For example, in a neural network, the synaptic connections form structural roles, but functional roles describe all possible synaptic activation patterns. One node can have only one structural role in a triad, but it can have up to three functional roles. In highly connected networks, all nodes are part of multiple motifs; therefore, they also have multiple structural and functional roles. By analysing the distribution of these roles, it is possible to draw conclusions about the roles and the patterns collaboration of the actors forming the network.

Collaborative practical work is an integral part of science education in classrooms all over the world. These experiments are usually done in dedicated classrooms or labs. The facilities include all the materials and tools needed to carry out the practical work. Generally, teachers view experiments as a way to generate new knowledge and assist in knowledge construction. However, practical work in itself does not lead to better learning outcomes (Abrahams & Millar, 2008; Berry, Mulhall, Gunstone, & Loughran, 1999). Work needs to be meaningfully applied for it to increase student learning.

Learning theories focus on student interactions that are isolated to the material world (i.e. labs and tools). For example, dialogic pedagogy is informed by actual practise and is grounded in classroom conditions, but it focuses only on verbal interactions between individuals (Mercer et al., 2004; Skidmore & Murakami, 2016). In practice, the tools enrich the dialogue between the students, but the connection between pedagogy and practice seems to be lacking. Hetherington, Hardman, Noakes and Wegerif (2018) propose a material-dialogic approach to bridge this gap between theory and practice. The approach combines Bakhtinian dialogic theory with Barad's agential realism.

According to Barad (2007), interaction presumes prior existence between independent entities. However, the notion of position cannot exist independently without an existing object. This means that position has meaning only in the phenomena in which it is observed, and this phenomena is conjunction of the object and the observation. Without pre-existence, there cannot be interaction. Instead, concepts become meaningful through entangled intra-actions. For Barad, the reality is composed of things-in-phenomena in a dynamic process of continuous intra-action. In the context of learning, this means that material affordances have an active role in meaning-making. Students still have actions and interactions, but together with the material affordances these become intra-actions.

Empirical research of this approach is still limited with only handfull research papers with material-dialogic in the title. For example, it has been shown that teachers do not explicitly consider intra-actions between dialogue and materials even though dialogic and material elements were present (Hetherington & Wegerif, 2018) and students' intra-actions with micro-blogging tools are able to deepen their dialogue and support conceptual development (Cook et.al, 2019). Additionally, material-dialogic approach has been used to study makerspaces (Kumpulainen & Kajamaa, 2019).

Producing network of students, teacher and material affordances allows the use of network analysis methods to study collaboration during practical work. Using these methods, it is possible to investigate roles of each actors as well as the intra-action patterns and show what is the role of materiality in the learning process. From these results, we can further develop theory regarding material-dialogic pedagogy and use the findings to improve teacher training.

Research Questions

This research includes three sub-studies. Study 1 develops network analysis methods in the context of online discussion. In studies 2 and 3, these methods are applied in digitally intensive project-based learning modules in upper secondary school physics.

Studies 2 and 3 hypothesise that intra-actions will exist, and the intra-action patterns will statistically differ from random patterns. These patterns have an effect on learning, and more active and more reciprocal patterns yield better learning outcomes.

Therefore, the research questions are as follows:

- How can intra-actions be observed?
- What kinds of patterns are formed (i.e. network roles for students, teachers and material tools)?
- Is there any connection between these patterns and learning outcomes? **Design and Methods**

Study 1 centred on pre-service teachers' online discussions of history of physics. Online discussions made it possible to develop network analysis methods in simple settings with straightforward network generation. The discussions were prestructured through guided questions. These questions and their instructions ensured that students could conduct discussions without facing technical difficulties that might distort the data. The discussions were reduced to temporal networks consisting of messages as nodes and edges representing responses (i.e. who answered to whom). Network analysis was then used to detect patterns in discussions in the form of roles. Studies 2 and 3 are part of a larger research project in which we will co-design, along with in-service teachers, a project-based learning (PBL) unit focusing on the mechanics of falling objects for first-year upper-secondary physics students. PBL is a form of situated learning, and it emphasizes active knowledge construction, social interactions and the use of cognitive tools (Krajcik & Shin, 2015). The cognitive tools, usually computer software, allow students to perform actions that are otherwise impossible. For example, by using a graph to visualize large datasets, students can find possible patterns in the dataset. Here, the computer and the graph are part of the material world—like the ink in Hetherington et al.'s (2018) chromatography example. The cognitive tools, coupled with social interactions, make PBL a plausible setting for observing learning situations where students use material tools as a part of their discussions even though PBL is not the actaul object of the study.

The mixed methods approach is used with video recording for data gathering. Qualitative methods are used to interpret student actions from the video data and generate networks. Quantitative analyses will be based on network methods developed in study 1.

Video analysis is usually divided into three different levels. With each level, the unit of analysis is smaller, but the focus is increased (Ash, 2007; Derry et al., 2010). In this research, the first level will be the general lesson outline, the second level includes significant events, (i.e. conducting investigations with digital tools within the lesson) and the third level includes precise descriptions of students' actions.

To streamline the analysis process, the first level of analysis was done through real-time observation. A simple observation tool was produced for this and used alongside video recording. The tool produces a timeline from a lesson that can then be used for choosing the relevant events for closer analysis.

From the selected video segments, students' actions will be coded into networks. A coding scheme will be formulated for this. This scheme will include students' verbal and non-verbal communications and actions relating to materiality, like looking at a computer screen and inputting information. Here, basic interaction structures (Heritage, 1984) will be used alongside the theoretical framework of materialdialogic pedagogy.

The generated network will consist of students, teachers, computers and other digital tools acting as nodes with actions and interactions between nodes representing edges that constitute intra-actions when combined. Network analysis should only be used when there is some sort of flux between the nodes (Zweig, 2016), and in this type of intra-action network, there is information that flows between human actors and digital tools. This flow of information produces the possibility of meaning-making for the actors.

The analysis for the intra-action patterns will be based on the methods developed in study 1. Similarly, this network will be temporal but edges are not bound to specific timestamps; they are more fluid and stretch from seconds to minutes. The roles are based on static motifs, but they can be used with time-slices. Additionally, static motifs can be extended to temporal network motifs (Masuda & Lambiotte, 2016), and this allows more accurate analysis of the dynamics within the network. Whether static or dynamic analysis should be used will be determined once the network is generated and its properties are explored.

Nature and Extent of Data

The data used in studies 2 and 3 consist of video data from co-designed PBL unit lessons and pre-post-test data used to assess students' learning. The first set of data has been gathered, but it is possible to obtain more data at a later stage as the project continues, if needed.

Two GoPro-cameras with external microphones were used to collect video data from the selected focus groups. There is one such group in each of the four units with two teachers, along with two groups in one expert teacher's unit. This resulted six groups with total of twenty students and forty hours of video. The video data was raw coded for the significant events during observation. The videos will be cut into segments totalling around ten hours for detailed coding.

Pre-post-test was a digital form consisting of items relating to conceptual and procedural knowledge. The test was administered for all classes with PBL units and three control groups. The test answers were downloaded to a table, graded and a preliminary analysis was conducted. Second grading and establishing inter-rater agreement will be done in the winter.

The PBL unit design and all data collection has been done with respect to the Finnish national curriculum and the ethical standards of the European Science Foundation (ESF). Participation has been voluntary, and all participants have provided signed permission. The data will be treated confidentially and as anonymously as possible for video-based research. The students, teachers or schools will not be identified in any publications.

Discussion

The development of network analysis methods was successful in study 1, and the methods were used to investigate how online discussions are affected by students' background knowledge. This has not been done before. The results revealed that role distributions were constant with students forming distinct two-node or three-node roles in each discussions. However, correlation with the background knowledge was not evident. One reason for this might be that structured online discussion does not foster naturally occurring interactions; therefore, patterns are clouded. The manuscript from study 1 has been submitted.

The results from studies 2 and 3 will provide valuable insight on how and when students use learning tools and how they intra-act with those tools. From this understanding, it is possible to formulate new pedagogical practices and further develop material-dialogic pedagogies. Results can then be directly used in teacher training to foster pre-service teachers' competence.

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Learning processes and conceptual development- On the way to photons

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Introduction and theoretical Background

Stating that *Quantum physics is not classical physics*, emphasizes on of the main barriers learning quantum physics must face (Franz & Müller, 2016). Hence, Kalkanis, Hadzidaki and Stavrou (2003) have claimed that a radical change of thinking, a conceptual change, is necessary to learn and understand quantum physics.

Current state of research shows that radical conceptual change rarely happens (Vosniadou & Skopeliti, 2014) This work presents two different, somehow contrasting perspectives on learning complex subjects like physics.

The first one is the *Framework* approach: Here, learning of physics is viewed as a slow and gradual temporal conceptual development in a broader range of contexts (Vosniadou & Skopeliti, 2014). In contrast, conceptual change in short learning sequences focused on single phenomena seem to be well described by the approach called *Knowledge in Pieces* (*KiP*) (diSessa, 1993), which assumes that explanatory schemes are determined by deeper concepts. Thus, the change of thinking on the level of change of conceptual understanding can be observed by the change of the usage of explanatory schemes for the given context (diSessa, 2017). The relative size of pieces of knowledge as well as the structure the pieces are ordered in and the context of knowledge components give a complex construct of knowledge. Nevertheless, despite of the complexity, tracing conceptual development has already been demonstrated by diSessa (2017) in classroom settings and by Rogge (2010) for pairs of students in laboratory studies.

To teach quantum physics in upper secondary school (Grade 12 or 13), while accepting the challenge of significant departure from classical domain we can rely on ready to use teaching concepts (Krijtenburg-Lewerissa, Pol, Brinkman, & van Joolingen, 2017; Müller, 2003). One of these is the *Münchener Unterrichtskonzept* (Munich quantum physics course) (Müller, 2003). The teaching sequences reduce quantum physics to five fundamental characteristical traits, called the *Wesenszüge* (traits of quantum physics): *Stochasticity,* *interference, results of measurements* and *complementary* as well as *entanglement* for multi-quanta systems (Küblbeck & Müller, 2002). The stringency of the interpretation of quantum physics is one of the pillars for an deeper understanding of quantum topics (Müller, 2003). The waiver of mathematical details fits the needs of students of upper secondary school and undergraduates (Krijtenburg-Lewerissa et al., 2017).

Because real true quantum physical experiments are of difficult access the Munich course is based on computer simulations and analogue experiments from classical physics to demonstrate quantum phenomena. Other approaches has to face similar difficulties (Krijtenburg-Lewerissa et al., 2017). On the other hand, real experiments are essential for physical epistemology and they are key components of science classes (Hofstein & Mamlok-Naaman, 2007). Science educational research shows, physics teachers are asking for real experiments eve for quantum physics (KrijtenburgLewerissa et al., 2017; Weber, 2018). Scholz, Friege and Weber (2018) suggest real undergraduate level true single photon experiments. The experiments, though designed for undergraduate labs, will unlikely enrich classroom physics in the near future simply due an experimental and financial expense and exceed the limitations of high schools.

The out-of-school lab foeXlab, the outreach-project of CRC 1227 DQ-*mat* has the opportunity to realise true single photon experiments. The straightforward experimental setup shown in Fig.1 (left hand side) combines a simple beam -splitter (OBS) experiment followed by a Michelson interferometer. It is easy to see that this setup

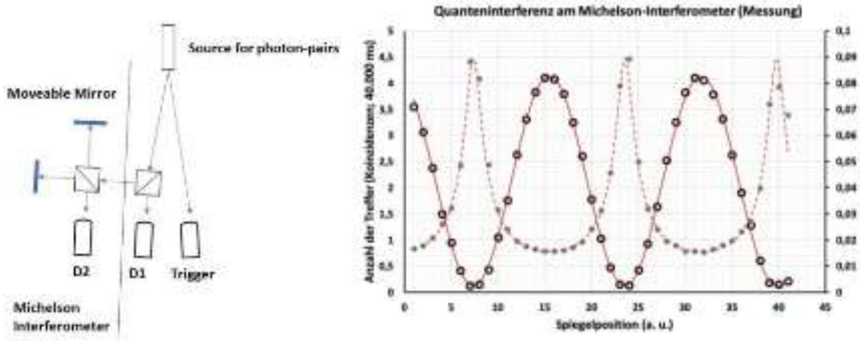

Fig.1: Left hand side: Sketch of experimental set up. Right hand side: Real Quantum data gathered at Output D2 of the interferometer (Coincidences Trigger & D2; red) and the measured measurement uncertainty (dashed line: theoretical prediction from poisson statistics) against the displacement of the moveable mirror.

should be suitable to overcome an naive wave particle dualism (Müller, 2003) and to pave the way to quantum physics (Scholz et al., 2018): In one setup the absence of coincidence clicks of detector D1and D2 (it proofs the unbreakability of photons) and the concurrent ability of a single photon to interfere (observable by a typically interference pattern of the signal from D2, when moving one of the mirrors; fig.1 right hand side), an experimental result that cannot be explained by classical physics. In a nutshell the experiment seems to be well suited to open a door to the quantum world. For this reason it is labelled a key experiment.

Now switching to learning perspective. There are two main reasons why students' primary concepts can be assumed to be classical: (1) Up to the 13th grade classroom physics solely covers classical physics. A bit physics of atoms, microsystems and duality (AMD-physics) will finish the course just before the Abitur (Kultusminister Konferenz, 2004).(2) Our daily experience, which is solely built up on classical physics. Thus, the experimental results are completely inconsistent with primary concepts of thinking. Following diSessa's theory of contextual micro-conceptual change, one could assume that a well performed key experiment, can induce a micro-conceptual change (e.q. from wave optics to single photon optics)

However, one can be doubtful on this idea. Some studies show, nine different reactions of students to contradictory data (Chinn & Brewer, 1998; Lin, 2007) and only one out of them leads to a conceptual change. The remaining reactions will maintain the initial concept. Even if quantum data are in contradiction with primary concepts, a conceptual change is very seldom.

Research desiderata - goal and questions

As outlined above, attempts to explain the results of the key experiment based on classical physics, will fail. Only quantum physics will help. Thus, it could be attractive to be able to use an appropriate tool to solve problems. May the key experiment such a tool to pave the way to quantum physics. To which extend that is possible is unknown until now.
So, the main research goal is to get information about the impact of the key experiment.
The research goal is (1) to explore primary explanatory schemes of the students and (2) to identify students' reaction to contradictory data. (3) We will try to find out something about changes in students' explanatory schemes. The research questions are:

Q1: What kind of primary explanatory schemes can be identified for the key experiment, while students start working on it?
Q2: To which extend students will recognize the contradiction between measured quantum data and classical physical proposals?

Q3: What kind of students' reaction ca be found, depending the contradiction of quantum data and classical physical explanations?
Q4: To which extend working with the key experiment will induce a micro-conceptual change?
Q5: To which extend does the working with the key experiment will help to develop an idea of basic quantum physical concepts?

Design and methods

Design

A study in a mixed methods design is conducted in order to answer the research questions. A pre- and post- paper-pencil test allows to define initial and final states of quantum physical content knowledge as well as to identify explanatory schemes at both states. To get insights into the conceptual development processes working with the key experiment, pairs of students will be observed in a laboratory study (c.f. Aufschnaiter, 2014). The whole work will be videotaped and subsequently analysed regarding students' reaction to contradictory quantum data and the sample of explanatory schemes used (Fig.2).

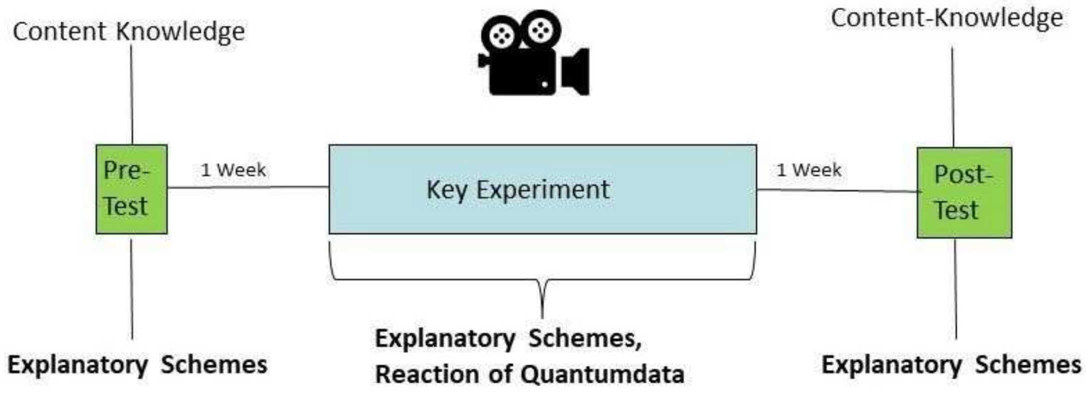

Fig. 2: Sketch of the design of the study. Bold marked: Qualitative Data.

Paper-pencil test Development of a paper-pencil test and a proof of validity

The test addresses content knowledge as well as explanatory schemes and consists of 29 multiple-choice items and four open questions. Most of the items used has been adapted from already existing proven tests (Bitzenbauer & Meyn, 2020; Di Uccio et al., 2019; Singh, 2008). All items cover the topics: *Quantum behaviour of electrons and photons*, *superposition and probability amplitudes*, *measurement* and *wave optics*. In addition, some items were developed.

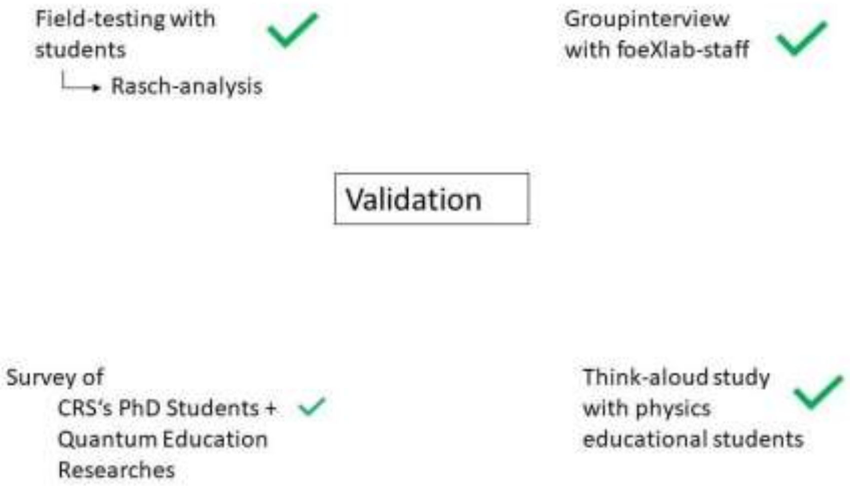

Fig. 3: Multistep survey of tests validity

As figure 3 shows, different surveys were conducted to validate the tests (for test validity examinations see Berger, Kulgemeyer and Lensing (2019) or Mesic et al. (2019)) .

In a first step the test items were distributed to a group of five teachers-to-be students. After answering the group discussed the items. Subsequently the discussion was analysed to identify a starting point for an improvement of test items.

In a next step the revised items were subject of a think-aloud interview study (cf. Sandmann, 2014) with eight physics teachers-to-be students. This study was intended to proof the internal consistency of the item answers and if the items would enhance the intended cognitive processes. Therefore, the students were asked to answer the questions in pairs. The discussions were audio taped to be transcribed and coded subsequently.

To prove the construct validity of the test, PhD-students of the CRC, as quantum experts, were asked to answer the test items. In addition, researchers in quantum education were asked to rate the quality of the items.

The first field study with physics students at the first and the third term followed in February 2020. Subsequently, based on a Rasch Analysis an unidimensional scale for item difficulty and persons' ability has been developed.

Analysis of qualitative data

For analysis the video tapes will be transcribed and analysed (qualitative content analysis (c.f. Schreier, 2014)).

As described so far, the analysis of the qualitative data will focus two aspects:

- Conceptual development: Coding system of Rogge (2010).
- Students' reaction to the contradiction between classical and quantum physics: Coding systems of Chinn and Brewer (1998) as well as that one of Lin (2007)

To ensure scientific quality criteria of coding and the coding system, parts of the transcripts will be double coded.

First Results

The validation of the questionnaire is finished, so the results should be presented briefly: The group interview, the think-aloud study and PhD-students answers reveal for problematic terms and sentences in the items. So, the items were carefully revised and, if possible, specific items were eliminated.

The item difficulty both types of interviews and the PhD-students' answers has been found to range from very easy to challenging items. As described so far, a Rasch analysis of results of the field study (February 2020 with 35 students for the first term,

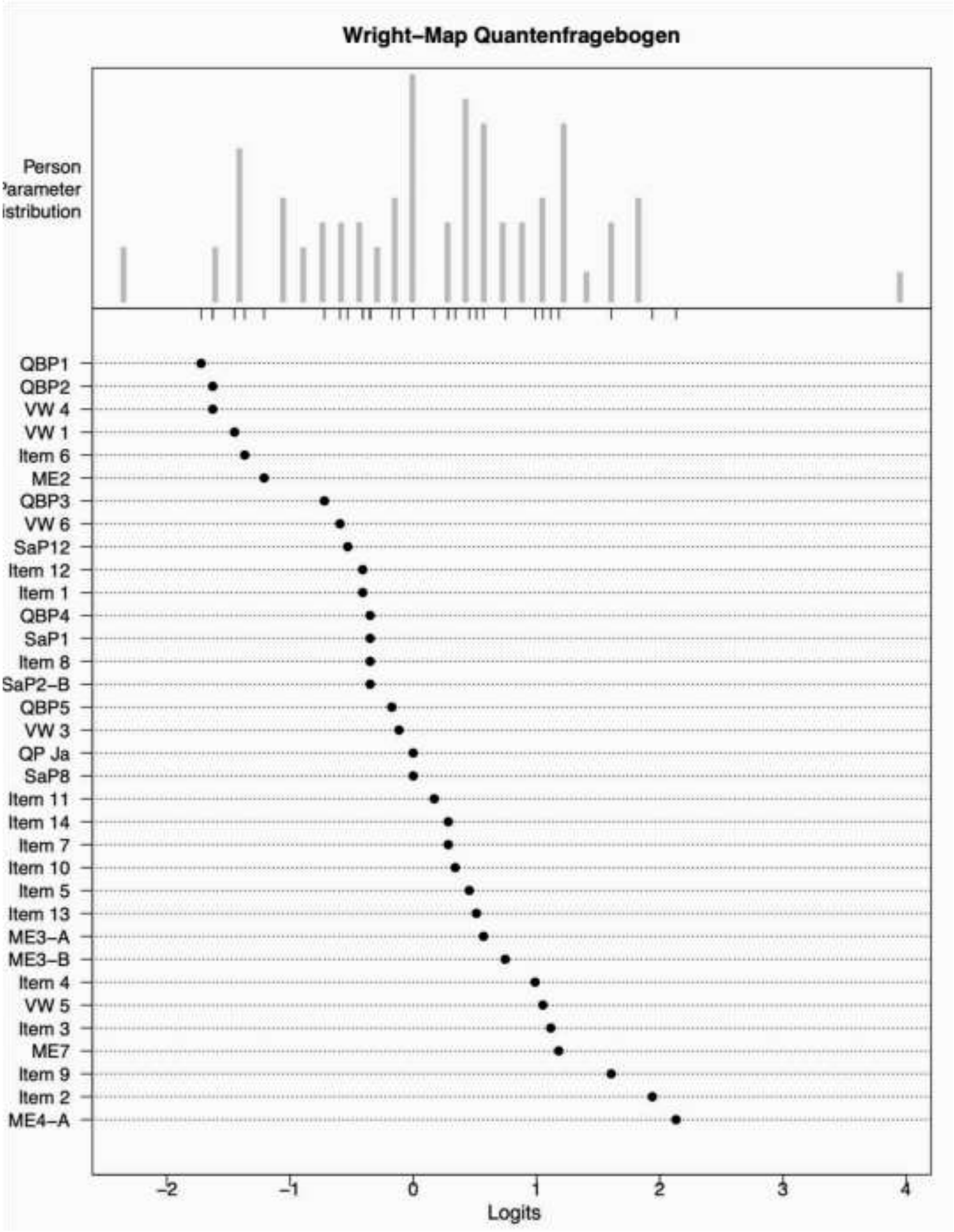

Fig 3. Person-Item Map of the questionnaires testing.

49 for the third term) has been used to determine the item difficulty on a unidimensional scale. As fig. 3 shows the range of the item difficulty, may be regarded as fitting the persons' ability. Only one student's ability is higher as the item QBP 5 and only two students are less able then the easiest item. The item-fit-statistics has been used to identify problematic items: The Item VW2 was identified as challenging. This goes along with the results of the previous interviews. So it was decided to eliminate that item.

Next steps and rough time scale

After the development of the quantum questionnaire the learning environment will be developed. The experimental laboratory part will be tested in the undergraduate practical lab of the faculty of mathematics and physics of the Leibniz University of Hannover. Because of the corona pandemic for summer term 2020 a virtual version is under consideration, which should start in April. The described version is rescheduled in the winter term 2020.

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Preservice physics teachers’ development of physics identities: The role of multiple representations

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Abstract: *This mixed-methods case study aimed to examine the development of preservice physics teachers’ physics identities through their participation in introductory physics course in Indonesia that incorporated the use of multiple representations (MR). Data were collected using three questionnaires (n=61) and semi-structured interviews (n=21) with the participants. The questionnaires were analyzed through a Wilcoxon signed ranks test in order to examine the changes of each component of preservice physics teachers’ physics identity. The interviews were analyzed through constant comparative analysis and by means of in-vivo coding techniques in order to explore the ways (if any) in which the participants’ physics identities developed. Preliminary findings showed that the use of MR supported the development of the participants’ physics identities and specific instructional practices were critical to the development of specific components of the participants’ physics identities. This study aims to contribute to the increasing knowledge base of physics identity by offering insights into how the development of physics identities might be supported through specially designed instructional practices.*

Key words: physics identity, multiple representations, physics education

A. Focus of the study

A set of studies from the last decade have provided evidence that students of all ages have generally negative attitudes towards physics and physics learning (e.g., Kessels et al., 2006; Stiles-Clarke & Macleod, 2016). One of the reasons why is because students encounter difficulties with problem-solving that involves the use of representations (e.g., Bollen et al., 2017). The use of multiple representations (MR) in physics teaching and how it might impact students’ problem-solving skills has received an increasing research interest in the past few years (e.g., Kohl & Finkelstein, 2017). The term multiple representations refers to the “combination of different modes of representation such as analogies, diagrams, graphs, cartoons, formulas, text, simulations, and gestures to communicate scientific concepts in scientific discourse and science learning” (Treagust et al., 2018, p.122). A review of related literature shows that an examination of how the use of MR might affect *social and affective* domains of learning and specifically physics identity development remains unexplored (Munfaridah et al., 2019). An exploration of physics identity and how it develops promises to offer useful insights into not only how students engage with physics but also how they develop conceptual understandings of physics (Avraamidou, 2019; Gosling, 2017).

By examining the impact that the use of MR in teaching might have on preservice teachers' physics identity development, I aim to address an existing gap in the literature about the kinds of instructional practices that could influence the development of preservice teachers' physics identities. This research goal is grounded within the assumption that specific instructional practices can significantly strengthen physics identity (Hazari et al., 2010). As well-documented in related literature: (a) MR can support the presentation of real-world problems in ways that enhance students' interest and engagement (Ainsworth, 1999); (b) MR have the potential to enhance students' conceptual understanding which is directly related to their competence and performance (e.g., Sutopo & Waldrip, 2014); and, (c) the use of questions requiring data representations in graphs and tables correlates with interest and recognition (Lock et al., 2015), which are prominent components of physics identity.

B. A Short Review of Relevant Literature

As conceptualized by Hazari et al. (2010), the construct of physics identity consists of four main components: (a) *competence:* being proficient in practices that are relevant to a particular context which in this study is physics; (b) *performance:* the ability to perform physics tasks, (c) *interest:* the desire to think about and understand physics; and, (d) *recognition:* perception by others as being a good physics student. Hazari et al. (2010) found a number of predictors related to high school experiences that influence undergraduate students' physics identity. Some of these predictors include conceptual understanding, connections of physics with real-world problems, and students' answering questions. Moreover, a related study by Hazari et al. (2007) showed that experiences involving longwritten problems, cumulative tests, father's encouragement, and family's belief that science leads to a better career provide a different prediction for the performance of the students, which is one of physics identity components. Another set of studies revealed that the way teachers position themselves in the classroom and the types of student-teacher interaction in the classroom can influence students' level and types of engagement and consequently the development of their physics identity (Berge et al., 2019).

In sum, research on physics identity illustrates a range of activities and experiences that might enhance the development of physics identity. Some of these activities are as follows: experience as a learning assistant (Close et al., 2016); participation in community practice in physics (Irving & Sayre, 2015); and, participating in the Physics Olympiad (Wulff et al., 2011). However, most of these activities are situated in contexts outside the formal school classroom, which leaves a gap of knowledge about the impact of classroombased activities on physics identity development. This is precisely what this study aims to do.

C. Purpose

The purpose of this study is to explore the impact of the use of MR, as form of a classroom practice focusing on real-world physics problems, on the development of preservice physics teachers' physics identities. The research questions that guided the study are the following:

(a) How did preservice physics teachers' physics identities develop over a specially designed course incorporating the use of MR?

(b) How did a group of preservice physics teachers perceive their experiences in learning with MR?

In what follows I describe the research context and I then discuss the outcomes of the preliminary data analysis related to the first research question. The data related to the second question are currently being analyzed.

D. Research Context

The introductory physics course that served as the context of this study was redesigned to incorporate the use of MR, as for example, the use of everyday-life demonstrations, pictures, diagrams, equations, and verbal reasoning. As defined by Sutopo and Waldrip (2014), the MR approach refers to the learning process where the students are able to construct evidence-based claims, critique and modify a representation, and then refine both initial claim and representation. A typical sequence of the learning process through a multiple representations approach is as follows: (a) the instructor provides problems and asks the students to solve the problems beginning with identifying known variables from the problems; (b) the students are asked to construct some representations such as diagrams, pictures, equations, and verbal descriptions through collaborative work in a group of two or three students; (c) the instructor moves around the groups and provides assistance according to written responses of the students; (d) the students share their work with others through a whole-classroom discussion. For the purpose of this study, the problems used by the instructor were presented with the use of MR, such as demonstration and video of the physics applications in everyday life, pictures, and diagrams in order to build a visual model for the students.

E. Research Design

I employed a mixed-method case study design to explore the development of preservice physics teachers' physics identity (n=61) through their participation in an introductory physics course that was taught through a MR approach. Quantitative and qualitative data were collected in three phases as shown in Figure 1.

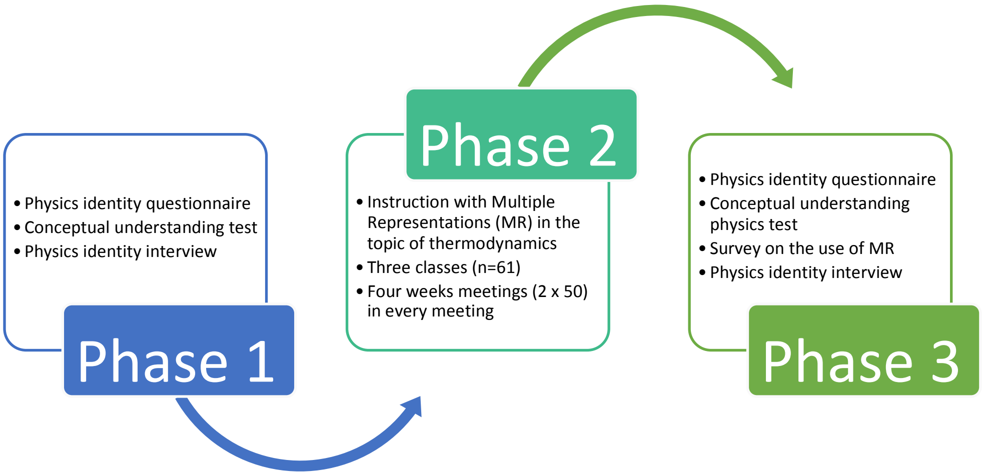

Figure 1. Research procedures

A Wilcoxon signed ranks test was used to check the difference between pre- and posttest scores of indicators of the four components of physics identity. The analysis of the students' interviews will be carried out at a later stage with the use of in-vivo coding techniques and ATLAS.ti software. Table 1 offers a summary of the kinds of data that were collected during the three phases.

Table 1. Data collected

No	Kinds of data	Participants	Many items/ durations	Descriptions
1	Pre-test physics identity (PI)	61	18 items	Questionnaire Likert-scale 1-6
2	Baseline thermodynamics	61	33 items	Multiple-choice
3	Post-test physics identity	61	18 items refer to PI	Questionnaire Likert-scale 1-6
4	Survey the use of MR	61	22 items	Questionnaire Likert-scale 1-5
5	Post thermodynamics	61	33 items	Multiple choice
6	Before learning process interview	21	Female: 11 Male: 10	30-45 minutes
7	After learning process interview	21	Female: 11 Male: 10	25-35 minutes

F. Preliminary Findings and Discussion

Enhancing competence through gaining physics conceptual understanding

The analysis of the data showed that the students had a better conceptual understanding after the learning process, which refers to their *competence* as physics learners. As shown in Table 2, there was a significant difference between students' conceptual understanding before and after the learning process. As Hazari et al. (2010) argued, students' conceptual understanding is one of the indicators that predict students' physics identity.

Enriching active interactions and performance

The analysis of the data indicated that only one indicator related to performance showed a significant difference. As shown in Table 2, there was a significant difference in the performance of students that were involved in small-group discussions. This result can be explained by the instructor's activities, which involved students in discussing in pairs the physics concept that had been presented through some demonstrations involving hands-on activities. As argued by Hazari et al. (2015), hands-on activities that have real-life contextual relevance is a kind of activity that is relevant to one of the cues that influence students' physics identity.

Enhancing interest in physics through the use of multiple representations

As shown in Table 2, some indicators related to *interest* were significantly enhanced after the learning process: (a) general interest in thermodynamics; (b) conducting own experiments; (c) understanding everyday life-sciences; and, (d) making scientific observations. As described earlier, the instructor involved some demonstrations related to the real-world application of thermodynamics concepts and emphasized the use of some representations during the learning process. Therefore, it is likely that students became more interested in specific aspects during the learning process. This finding is in agreement with existing literature pointing to that real-world problems might enhance students' interest development and engagement (Ainsworth, 1999).

Table 2. Mean score of physics identity components (N = 61)

Physics Identity Dimensions	Pre *M* (SD)	Post *M* (SD)
Competence		
The score of conceptual understanding test (Thermodynamics Concept Survey)	1.38 (0.55)*	2.26 (1.01)*
Performance		
You taught your classmates	1.70 (1.56)	2.10 (1.84)
Doing hands-on activities	3.67 (1.09)	3.87 (2.13)
Involve in small group discussion	3.51 (1.81)*	4.16 (1.86)*
Asking questions	2.00 (1.56)	1.90 (1.82)
Answering questions	1.89 (1.58)	1.72 (1.55)
Interest		
General interest in the topic of thermodynamics	3.75 (0.99)*	4.16 (0.90)*
Conducting your own experiments	3.98 (1.44)*	4.41 (1.33)*
Understanding natural phenomena	4.75 (0.99)	4.85 (1.14)
Understanding everyday life-sciences	4.62 (0.99)*	4.97 (1.06)*
Explaining things with facts	4.67 (1.08)	4.85 (1.03)
Using mathematics	4.31 (1.23)	4.18 (1.20)
Telling others about science concepts	4.31 (1.22)	4.51 (1.29)
Making scientific observations	4.03 (1.25)*	4.57 (1.13)*
Wanting to know more science	4.90 (1.06)	5.03 (1.12)
Graduating from college with honors	5.84 (0.49)	5.72 (0.66)
Recognition		
Recognition by yourself	3.41 (1.02)*	3.62 (0.97)*
Recognition by parents/ relatives/ friends	4.23 (0.95)	4.00 (1.06)
Recognition by teacher	4.08 (1.24)*	3.67 (1.18)*

*it has significance different the value of each item before and after the learning process

G. Significance

This study sheds light on the ways in which preservice teachers' identity development might be supported through the use of MR as an instructional practice. The findings are significant for practice given that they offer concrete evidence that the use of MR can support preservice physics teachers' physics identity development and have implications for curriculum design. From a research perspective, the findings are significant as they contribute to an existing gap in the knowledge base on instructional practices that might support physics identity development.

H. Timeline

The second research question will be addressed through the analysis of the interview data with the participants about their experiences learning with MR approach. Table 3 shows the description of the research timeline for this study.

Table 3. Research timeline

Activities	Time frame
Quantitative data analysis (i.e., questionnaire of physics identity, thermodynamics test, and survey of the use MR)	
Screening and cleaning of raw data	July – August 2019
Data transformations with statistical software, SPSS	August – September 2019
Carry out initial statistical analysis of transformed data and interpret results of statistical analysis	October – November 2019
Perform descriptive and inferential analysis	December 2019 – January 2020
Make inferences and interpretation above	February 2020
Distilling inferences/findings into conclusions	March 2020
Present research findings in tables, figures, and graphs	April 2020
Qualitative data analysis (i.e., interview before and after the learning process)	
Finishing and re-read the audio transcripts	May 2020
Familiarisation	June – July 2020
Developing coding scheme	August – September 2020
Data analysis	October 2020 – January 2021
Writing and manuscript production	January 2021 – August 2021

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Cultivating Students’ Mechanistic Reasoning through Students-generated Stop Motion Animations

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ABSTRACT

Mechanistic reasoning is a valuable thinking strategy for students trying to make sense of physical phenomena. Mechanistic reasoning, in which phenomena are explained in term of “entities” and “activities of entities”, can be stimulated by asking students to construct models. This study employs a specific type of modeling tool, the stop-motion animation, to help students develop mechanistic reasoning. 9th-grade students were asked to create a stop-motion animation of a football being kicked and to explain their model afterwards. The entire process was studied using semi-structured interviews. Data analysis revealed that students’ levels of mechanistic reasoning increased during the construction of stop-motion animations and their subsequent explanation. Furthermore, students appear to be stimulated to use more abstract reasoning, i.e., make more use of abstract entities, during the course of the process.

STUDY FOCUS

Many studies in science education show that engaging students in constructing a model in order to make sense of a phenomenon is a powerful pedagogical tool to develop students’ scientific reasoning (Ainsworth, Prain, & Tytler, 2011; Krist, Schwarz, & Reiser, 2019; Prain & Tytler, 2012). One of the key elements of scientific reasoning is mechanistic reasoning, in which natural phenomena are explained in terms of entities and activities of those entities (Russ, Scherr, Hammer, & Mikeska, 2008). For instance, the entity “gravity” has the activity of “pulling an object toward to the earth”. However, supporting mechanistic reasoning in students’ explanations of a phenomenon is notoriously challenging. For example, Schwarz, Ke, Lee, & Rosenberg (2014) found that many students generating a model of evaporation focused on “what’s happening” and were only able to provide a global macroscopic account, i.e., the change of state of the matter, without referring to entities like water molecules. De Andrade, Freire, & Baptista, (2019) also found that most of the students, when asked to construct explanations about the condensation of water on the surface of a cold can, used macroscopic entities rather than microscopic entities. Additionally, Schwarz et al., (2014) revealed that even if students knew of the existence of water molecules, as a microscopic entity, and used this entity for their explanations, their explanations were still not fully mechanistic. For instance, students were not able to explain evaporation in terms of water particles spreading out into the air when liquid water comes into contact with air. De Andrade, Freire, & Baptista, (2019) also found that most of students' explanations of the condensation of water were classified as non-explanation that described what happened without presenting underlying causes for that phenomenon, because students faced difficulties in organizing their ideas and structuring a sequence of events into a causal story.

Students' reasoning on micro and macro level in mechanistic explanations would not occur spontaneously, according to de Andrade, Freire, & Baptista, (2019). Rather, students needed to be supported and guided by the teacher for long enough periods of time. Honwad et al., (2010) demonstrated that using a modeling environment that pushed the students into thinking about structure, behavior, and function, as the way of organizing of entities and activities those entities, could stimulate them to think about the interaction between visible and invisible entities. Even though such reasoning has not been mechanistic yet, we think that this is important first step toward mechanistic reasoning, which is characterized by a set of causal processes of how entities bring about a phenomenon (Russ, Coffey, Hammer, & Hutchison, 2009).

We argue that students need to have modeling tools that guide them through model construction and force them to incorporate visible and invisible entities in considering the deep processes giving rise to a phenomenon. In this study we use stop-motion animations, as a modeling tool, to address this issue. In stop-motion animation, students create "a series of frames so each frame as alternation of the previous one (Ainsworth, 2008)" thus this technique allows them to build a step-by-step explanation of a certain physical phenomenon. Additionally, because every frame is a single step as part of the whole processes underlying a phenomenon (Hoban, Loughran, & Nielsen, 2011), students are forced to pay attention to the processes in depth. We argue that it is the step-by-step nature of the process that forces students to consider all the steps and combine all moments together to depict the process underpinning a phenomenon. Therefore, the goal of this study is to examine how stop-motion animation created by students induces them to reason mechanistically.

A SHORT REVIEW OF RELEVANT LITERATURE

Mechanistic reasoning plays an essential role in developing scientific explanation about phenomena. Mechanistic reasoning provides a causal explanatory account that can describe not only scientific ideas, such as an idea about phase change of matter, but also figures out the underlying mechanism behind these ideas (Krist et al., 2019). As a framework for mechanistic reasoning developed by (Machamer, Darden, & Craver, 2000; Russ et al., 2008), two aspects are essential to mechanistic reasoning: *Entities and Activities*. Machamertt et al., (2000) stated that mechanisms are “*Entities* and *activities* organized such that they are productive of regular changes from start or setup to finish or termination conditions”. Russ et al., (2008) introduced seven levels of sophistication for mechanistic reasoning: (1) describing the target phenomenon, (2) identifying setup conditions, (3) using entities, (4) activities of entities, (5) properties of entities, (6) organization of entities and (7) chaining. *Entities* are agents that affect the mechanisms to occur. *Activities* are what *Entities* do to produce the change. For example, in the phenomenon about a ball moving with a parabolic trajectory, *gravity* is the entity and *pulling the ball down* is *the Activity* of *gravity* that cause the ball to go down. *Entities* have *Properties* allowing them to engage in specific activities. Chaining, as the highest level of mechanistic reasoning, is a causal structure that makes a claim about why a phenomenon comes about.

To develop students’ mechanistic reasoning, we set up an instructional task that asks students to create a model of a phenomenon through stop-motion animation. The elements of stop-motion animation are : (1) a series of individual images, called frame; (2) In the construction of a specific frame students must be mindful of the previous and the upcoming frame; (3) each frame must be placed in sequence so that each frame looks like an alteration of the previous one (Hoban et al., 2011). Because each frame in the animation represents one particular moment, each frame presents a specific condition of the entities involved. In our example, each frame presents the different height of the ball (entity).

Arranging all frames in sequence stimulates students to think about what is exactly changing and why or how the changes can occur. To do so, relevant activities of the entities, and the other aspects of mechanistic reasoning must be involved. Therefore, we theorize that when students construct a stop-motion animation, as a model for understanding the emergence of a phenomenon, the process of construction induces them to reason mechanistically.

RESEARCH QUESTION

The research questions that we would address are: How does stop-motion animation force students to reason mechanistically? And which levels of mechanistic reasoning are attained using stop-motion animation?

METHODOLOGY Participants and data collection

The main aim of this study is to explore the affordance of stop-motion animation for supporting students' mechanistic reasoning. To deal with this endeavor, a case study (Creswell & Poth, 2018; Yin, 2013) was conducted with ten ninth-grade students from an international secondary school located in Rotterdam, Netherlands. Students were randomly selected. The interview protocol was: (1) Introduction (10 minutes), students were introduced to the HP Sprout computer and how to use it for creating stop motion animations, (2) Model creation (15 minutes), students created the animation without guidance, and (3) Discussion (35 minutes), employing think-aloud interviews (Ericsson & Simon, 1998) in order to trace students' ideas behind the construction of their animation. All the parts were audiotaped and videotaped. The animation artifacts were collected..

Data Analysis

To address the research questions, we analyzed the animation artifacts and the students' interview responses. The interviews were transcribed and coded top-down using a coding scheme for mechanistic reasoning developed by Russ et al., (2008). We did add one feature in that we added an extra code to every level of mechanistic reasoning in Russ et al: every level was classified either concrete or abstract. For example: " The foot kicks the ball" was coded as concrete, since it only involved tangible entities, whereas " as the ball goes up, energy is decreasing" was coded as abstract, since it involves the abstract, intangible entity of energy.

In analyzing students' utterances, students' conceptual correctness was not coded as such. We only assessed the mechanistic nature of students' reasoning in their explanation of their stop-motion animation. The number of utterances on each level (1-7) and abstraction were counted. Every level of mechanistic aspect was classified into two different aspect: concrete and abstract reasoning. About 10% of the coding was checked with a second coder from the same institute. Intercoder reliability was found to be 0,79.

PRELIMINARY FINDINGS

We found that all ten students created a stop-motion animation of the balls movement that resembled a parabolic trajectory. We then analyzed students utterances relating to the process of the construction of the individual frames. The process of construction of the animation was analyzed by dividing it in three phases: (1) Phase A, consisting of the kick (frame 1 and 2 in Figure 1) and the initial straight movement (frame 3); (2) Phase B (frame 4 and 5), when the ball starts to level out up to the point where it reaches maximum height; and (3) Phase C, consisting Frame 6, 7 and 8, describing the downward motion until the ball reaches the ground.

Figure 1. a number of frames of stop-motion animation about the balls' movement with parabolic trajectory. Phase A: the first three frames; Phase B: the frame 4 and 5; Phase C: the last three frames.

Figure 2 shows the level of students mechanistic reasoning with abstract or concrete utterances in each phase. Based on students utterances in Phase A, the students were classified into two groups: (1) a concrete group, only consisting of students who only involved concrete aspects in their reasoning and (2) an abstract group of students who also included abstract utterances. Both groups were capable of reasoning about chaining in Phase A, as the highest level (level 7), but in different ways. In concrete group, students said that

"*…we can see here [1st position of the ball], that he kicks it with sort of upward angle [2nd frame]… that makes it go that way, and arch on that direction [3rd frame]*".

The student only employed a concrete entity (level 3) "the foot" and a concrete activity of *the foot* (level 4) "kick the ball", as well as setting up an initial condition "1st position" (concrete; level 2). So even though chaining was present, it was on a wholly concrete level. In the abstract group, the student used the abstract entity "force" in reasoning by stating that

"…. because the force is from the bottom [2nd frame], …. the person who is kicking the ball, he is giving like the force to the ball, that makes the ball go higher [3rd frame]".

In Phase A, from both excerpts, we found that the concrete entity and activity "the foot and kick" were used in students reasoning.

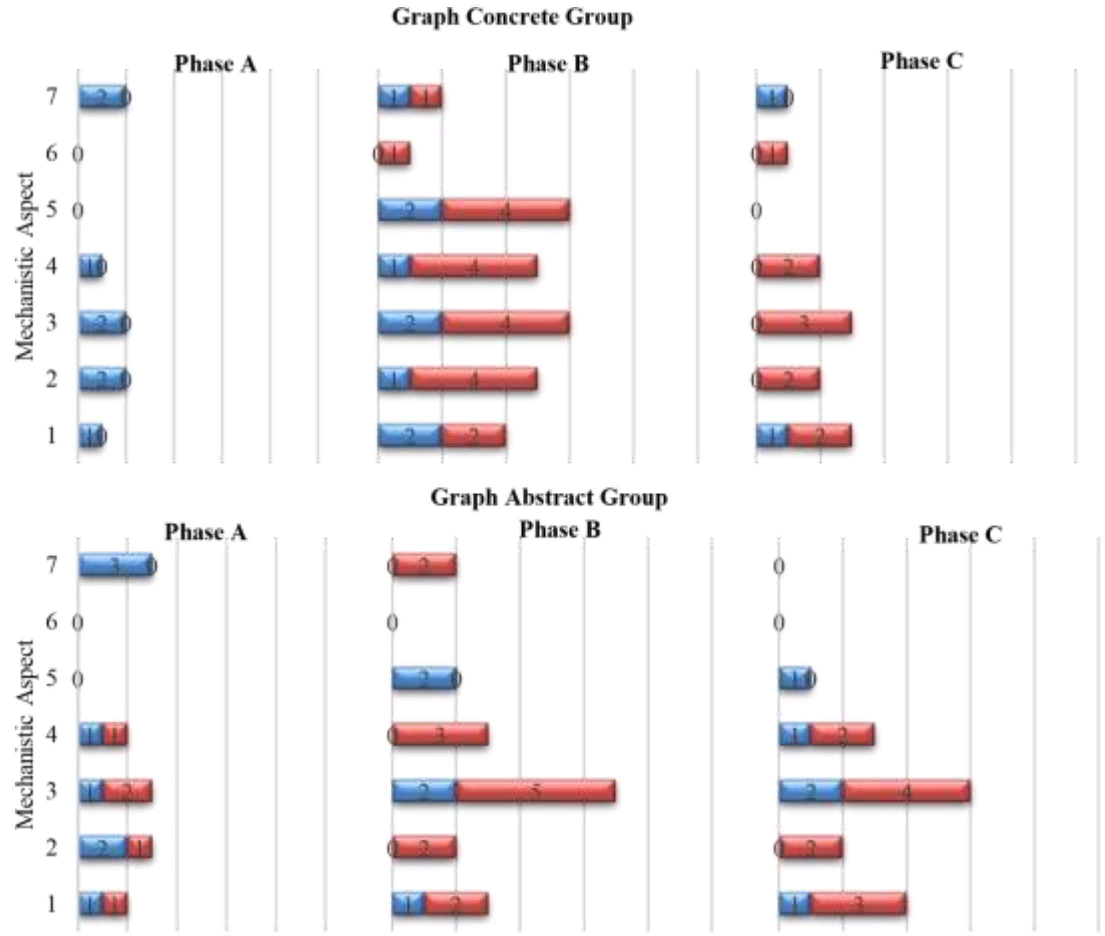

Figure 2. the level of students reasoning in two different groups: concrete group and Abstract Group.

As can be seen in Figure 2, both groups ended up using abstract entities and activities in their reasoning in Phase B and C. For example, in the concrete group, when asked to explain why the direction is changed as the ball goes up, the student stated that *"…when right from the kick off [1st frame], it will have a momentum, and it [momentum] will lose, due to air resistance and gravity trying to pull it back down [as the ball moves up with curved line]. Since it [the ball] has to go, since it is going up, it slows down [the balls' speed slows down], because it [ball] needs to push all the particle of air out of your way and also needs to fight the gravity which is very powerful of force…".*

From this excerpt we found that in Phase B the student started to employ abstract entity, such as gravity, momentum, and air particles. We argue that it was the confrontation with the change in direction of the ball from one frame to the next, without the ball being in direct contact with the foot. This condition stimulated the student to think about the other abstract entities causing the change in direction. So, the stop-motion animation procedure forced this student to employ abstract entities even though the they started off with purely concrete ones.

PRELIMINARY CONCLUSION

In this ongoing work, we assert that stop-motion animation as a modeling tool helps students increase their levels of mechanistic reasoning and stimulates them to use more abstract reasoning.

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The Framework for Inclusive Science Education

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Focus of the study

My dissertation project, which is entitled Framework for Inclusive Science Education, is part of the research project Teaching Science Education Inclusively (German acronym: Nawi-In), funded by the German Federal Ministry of Education and Research and involving three early-career researchers. Taken as a whole, the project examines how teacher students acquire and develop the professional competencies regarding inclusive science education. My dissertation project aims to identify criteria for assessing preservice teachers' professional competencies in implementing and reflecting inclusive science education and findings will be used for all subsequent analyses in the Nawi-In project.

The framework for inclusive science education seeks to relate three dimensions: science education, inclusive pedagogy, and the quality of professional competencies in analysing inclusive science education. I focus on the connection between science education and inclusive pedagogy, and fill this connection within the framework contextually with categories. This intersection represents a major challenge in research and practice. The definition for inclusive science education shows this challenge with the following quotation:

> Science education fosters inclusion by facilitating participation in science specific learning processes for all learners. By appreciating the diversity and individual prerequisites, science education involves individual and joint teaching and learning processes to promote scientific literacy. (Walkowiak, Rott, Abels, & Nehring, 2018, p. 269).

On the one hand, this definition implies that inclusive approaches are compatible with science education. On the other hand, researchers and educators would argue that on this general level the relation between inclusion and science education is not concrete enough. It is not explicated what the science specific learning really is and how it connects to inclusive pedagogy. This dissertation project is the first to explore the relationship between science education and inclusive pedagogy based on specific categories, which make inclusive science education ascertainable for research or rather for the analysis of school practice and to assess if and to what extent inclusive classroom settings have been created.

The categories focus on the connection between key dimensions of science education (e.g., experiments, phenomena, or safety issues in the science classroom) and those of inclusive pedagogy (e.g., learning in collaboration, differentiation, or scaffolding). This dissertation project aims to identify these categories as they apply to classroom settings, to operationalise the categories, and to validate the categories and later the whole framework as well.

Science education has been considered as important in the context of inclusion (Abels, 2015; Scruggs, Mastropieri, & Okolo, 2008; Southerland & Gess-Newsome, 1999; Villanueva, Taylor, Therrien, & Hand, 2012). Even though the notion of science for all suggests that all pupils, irrespective of their individuality, should engage in and understand the practice of science; still current instructional practices do not include all pupils (Villanueva et al., 2012). Teachers have a lack of knowledge of teaching science inclusively, have limited education in this field, and a lack of confidence in teaching science in inclusive classes (Mumba, Banda, & Chabalengula, 2015). The paradox in this case is that there is yet no criteria which provide comprehensive guidance for teachers on how to implement inclusive science education, nor is there sufficient frameworks to support researchers in analysing inclusive science education. The aim of my dissertation project is to fill this gap.

Review of relevant literature

The connection of science education with inclusion starts with the definition of scientific literacy as a goal for all pupils. The OECD (2019) classifies scientific literacy as content knowledge, procedural knowledge and epistemic knowledge. To illustrate, content knowledge includes scientific theory, facts, concepts, models and representations, predictions, hypotheses and potential implications of scientific knowledge for society (ibid.). The procedural knowledge describes identifying and exploring scientific questions, evaluating, ensuring reliability, objectivity and generalisability of explanations (ibid.). Hence, epistemic knowledge means interpreting data, drawing conclusions, assumptions, evidence, reasoning, arguing and using different sources for evidence
(ibid.).

Then to define inclusion as a “principle approach to action in education and society”, it means to value everyone equally, to reduce exclusion, minimise all barriers and to assure participation for all pupils (Booth, Ainscow, & Kingston, 2006). Furthermore, it involves the recognition of differences and similarities between the pupils, to make sure, everyone can respond to shared experience (ibid.). With the

“Framework for Participation” Black-Hawkins (2010) found a research tool for exploring the relationship between achievement and inclusion in schools. The aim of the framework is to apply it on school practice “to examine ways in which the cultures of a school support and/or impede opportunities for all its members to participate in the life of that school” (Black-Hawkins, 2010, p. 26).

Black-Hawkins operationalizes the implementation of inclusion by participation and defines three sections of it: access as being there, collaboration as learning together and the recognition and acceptance of diversity (ibid.). For instance, access as being there means for science education that the science classroom has passable ways between the tables, everybody can operate the devices (e.g., height-adjustable sinks and vents) and the teacher ensures the safety for all (e.g., with plastic instead of glass beakers, heating plate instead of gas burner) (Thomsen, 2017). In addition, pupils can communicate in the same technical language through different approaches (Ok, Hughes, & Boklage, 2017). Furthermore, collaboration as learning together summarises that pupils do not only learn together in one group, but also deal with the same scientific content on their individual level. With inquiry-based learning for example, pupils have the opportunity to explore scientific questions and concepts according to their interest. Pupils can explore their scientific questions, which refer to a common learning object, either in group work or individually. (Abels, 2014). Moreover, there is a variety of research about teachers’ belief regarding inclusive education (e.g., Garriott, Miller, & Snyder, 2003; Hellmich & Görel, 2014), but recognition and acceptance of diversity are rarely evaluated in connection with inclusive science education (e.g., Fränkel, 2019; Spektor-Levy & Yifrach, 2019; Simon, 2019). When teachers get in direct contact with inclusive classrooms, their beliefs are more positive than the beliefs of those teachers with less experience in this context (Hellmich & Görel, 2014). It is therefore important that future teachers have the opportunity to gain practical experience during their studies, so that recognition and acceptance of diversity can be fulfilled (Black-Hawkins, 2010).

Whereas in research there is usually a focus on a single approach regarding inclusive science education (e.g. a focus on inclusive experiments, inclusive learning environment or inclusion of pupils with certain needs), Stinken-Rösner et al. (in review) established a scheme that theoretically connects perspectives of inclusive pedagogy (acknowledging diversity, recognizing barriers, enabling participation (UNESCO, 2005)) with perspectives of science education (learning science, learning about science, doing science, addressing socio-scientific issues (Hodson, 2014)). With this theoretical scheme the authors call for new approaches as the connecting parts of the scheme, which actually depict inclusive science education, have not been filled with content yet. However, the aim of this dissertation project is to fill the connecting parts of inclusion and science education with categories derived from literature and research.

Research Questions

This dissertation project proposes a framework that allows researchers to investigate inclusive science education and is guided by two distinct research questions:

1. Which teacher-related characteristics predict the implementation of inclusive science education?
    a. Which predictors have already acquired the status of an indicator?
2. Which teacher-related characteristics of inclusive science education do teacher students show in their own teaching?
3.

The research aim is to develop a framework structuring the theoretically and empirically based teacher-related characteristics of inclusive science education given in the literature. These characteristics describe teacher competencies, how teachers can perform in relation to science teaching to make it inclusive. The framework will be validated through analyses of video data of pre- and in-service teachers implementing inclusive approaches in science classrooms. At the same time, I analyse the videos with regard to the teacher students' competencies to teach inclusive science education. Attending the summer school would allow me the opportunity to discuss convenient sub-questions for my dissertation project.

Research Design, Methodology, Methods, Nature and Extend of Data

The superordinate method describes the establishment and validation of an analysis instrument for the evaluation of inclusive science contents (literature, school practice and reflection on practice).

This dissertation project involves three major steps. The first one is to map the field by conducting a systematic literature review (Fink, 2009) with an emphasis on criteria for practicing and analysing inclusive science education. To consider the literature about inclusive science education, I used the methodology of a systematic literature review as a typical way of mapping the field (Fink, 2009). Using a qualitative content analysis with technical support of MAXQDA (version 2018.2), I derived categories from the literature (Kuckartz, 2018). The sample (n=286) of my search is composed of English and German literature relating to inclusive science education in primary and secondary school. The quantitative description of the sample shows that even though the number of publications increased in the last decade in this field only one third of the reviewed papers is empirical whereas two thirds are still theoretic.

The second section of my dissertation project will require testing and validating of the proposed framework using empirical evidence with the analysis of videos of future and current teachers in inclusive science classrooms. In the Nawi-In project, teacher students will acquire a theoretical understanding of inclusive science education before their teaching assignments. During a six-month internship, teacher students teach inclusive science lessons that they have designed on their own. Guidance for the 32 teacher students will be provided by mentors, who work at local schools cooperating with the university. Lessons by the teacher students will be videotaped. In a next step, a qualitative content analysis using the previously developed categories will be conducted (Kuckartz, 2018). The results will be used to revise and validate the categories. At the moment, the analysis of the literature is still ongoing and more complex than expected.

In the third step, the categories of inclusive science education will be structured within the intended Framework for Inclusive Science Education (fig. 1). Here, the connections between inclusive pedagogy and science education will feature the categories (grey part in fig. 1).

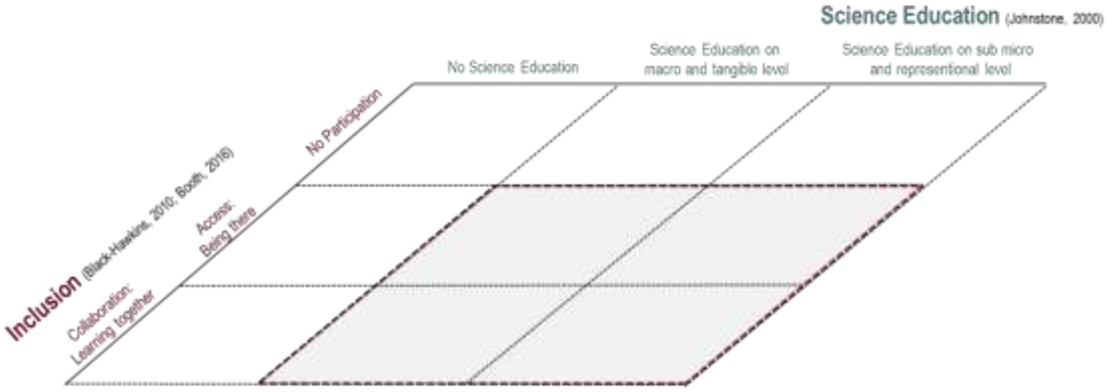

Figure 1: Framework of Inclusive Science Education (Base Level)

The axis of inclusive pedagogy depicts the dimensions of the Framework of Participation by Black-Hawkins (2010). The axis also shows the science education could be arranged using the levels of thought by Johnstone (2000), which distinguishes the scientific content between a directly experienceable, observable level and an abstract level of imagination. It must be justifiable how the categories are arranged within the framework, as other researchers will apply the framework on their data and for further analysis in the field of inclusive science education. Therefore, I will use a communicative verification for the arrangement by expert discussion. The Framework for Inclusive Science Education will approximately be finished by autumn 2020.

Discussion

Whilst the analysis of the literature is ongoing, at this stage, the categories can provide some initial guidance on how inclusive science education could be planned, realised and analysed. At this stage, they cannot be used to evaluate successful inclusive science education. First, most of them are based on theoretical work and have not been tested empirically yet. To achieve the status of an indicator, which would be a reliable and empirically tested operator to identify inclusive science education, further research must give evidence for the categories. Therefore, the categories have a status of predictors, since they can make a preliminary assumption as to which characteristics can lead to the success of inclusive science education. Second, even if the categories indicate inclusive moments in science education with a high degree of certainty, I will not be able to proof, if the implementation of inclusion in science class is successful, and this is no aim of this project. To answer this question, research has to include pupils' experiences, feelings and learning progresses. Referring back to Black-Hawkin's Framework for Participation (2010), with the predictors I can analyse basic conditions to elaborate the access to and the collaboration within science class. More specifically, we can observe if a scientific classroom or the facilities within this room give pupils the possibility to be present in science class. Similarly, we can observe when teachers apply methods, in which pupils do cooperative learning (e.g. do experiments in group work). The collaboration after Black-Hawkins (2010) even goes further. It also describes that pupils deal with the same subject matter based on their individual learning objectives. With the predictors, we can observe if teachers or teacher students plan and apply learning environments with the same subject matter and individual learning objectives for all, but we cannot proof if the methods actually reach the pupils. At this point, the predictors are not objective and encompassing enough. In this case, the evaluation of the pupils' learning progress might help to indicate collaboration. Furthermore from the analyses of my colleagues in the Nawi-In project, I can obtain information about the recognition of diversity through the students' reflections on inclusive science education, as the students are supposed to identify inclusive moments in science education. With the predictors, I am not able to evaluate the teacher students' acceptance of diversity, which is the third category of Black-Hawkins' Framework to indicate successful inclusion. In this case, I use further information about the attitudes and beliefs of the protagonists in the classroom. As my colleagues from the Nawi-In project analyse the beliefs and self-efficacy of the students using questionnaires, I will have access to the teacher component in the classroom. Hence, to identify the successful implementation of inclusion in science class, I would have to analyse the schoolmates' beliefs about inclusion and the pupils' feelings about feeling accepted and valued in class. To which extend do students or teachers recognise the pupils needs and potentials, to which extend do they have the competencies to evade the individual potentials and to which extend do the pupils feel valued? Applying the predictors in a school setting is a step in expanding on the knowledge of inclusive science education in school contexts. It is important to note here that studies have shown that there is a difference between the competencies teachers have acquired and their actual performance in class (Korthagen, 2010). This finding will have to be considered when testing the framework, which will have to be operationalized prior to observing teachers' performances in class. The predictors within the framework need to be verbalized so that teachers' competencies become observable. At the same time, these categories must be validated to make them applicable. The challenge here will be to find the right measure between observation and interpretation as well as to define this interaction for the predictors.

At the time of writing, I have access to 64 video recordings of 45-minute lessons by teacher students. Given this large amount of data, it will be necessary to identify selection criteria for choosing those videos which will be analysed in greater detail. This criteria has yet to be identified, and it is also not clear whether this data and related analyses will suffice when it comes to validating the framework.

As I focus on the teacher students' competences and performances, I will not be able to test whether their teaching is successful and to what extent. To measure the impact, I would have to examine, among other aspects, what teacher students do, how and what they learn, how they participate in class or whether they feel integrated when teacher students apply the categories for inclusive science education. The science classroom is a dynamic learning environment characterized by complex social relations, and it is therefore necessary to constantly adapt one's teaching and, more specifically, one's use of the categories to changing conditions to create an inclusive classroom situation.

Preliminary Findings

20 % of the sample have been analysed, and sixteen main categories with subcategories, codes, and subcodes have been developed. Preliminary results of the analysis point to gaps especially in cases in which scientific subject content is being addressed at increasingly abstract, theoretical levels (e.g., theory of atoms). Despite these gaps, the analytical framework currently under development is already providing preliminary guidance to, for example, science teacher students who want to develop and teach in inclusive classrooms.

Prior to the ESERA summer school commencing, I plan to have analysed all titles of my literature sample with qualitative content analysis (Kuckartz, 2016). Qualitative content analysis benefit from exchange and bringing different expertise into discussions, as the analysis framework with the categories is a dynamic system that develops in ongoing processes. During the summer school I would like to critically discuss my methodological approach, the results and how to integrate them into the framework. It would also be helpful to reflect on the application of the categories and the framework on the videos of school practice.

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Integrating extracurricular learning by implementation of virtual labs in schools

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Abstract

Successful transfer of a digital innovation into schools depends on school structures, teachers' willingness and the innovation itself. In our case, the innovation consists of virtual laboratories for pre- and post-work on experiments in science education. As it is our aim to identify potential barriers for the implementation, we address the influencing factors derived from literature in a dyadic study. School structures and teachers' readiness are considered via a delphi technique including quantitative questionnaire data and qual-itative guideline interviews. Our learning environment is evaluated by students' response to the virtual labs. Regarding this, data are collected by recurring questionnaires, whereas learning processes are captured and analysed by videography. Drawing on our findings, we are going to provide pedagogical concepts to encourage the implementation of our virtual labs on the topic of water analysis.

Problem

Out-of-school education benefits learners and teachers alike. However, certain challenges in applying extracurricular learning settings must not be neglected (Karpa, Lübbecke & Adam, 2015). The effectiveness of learning in out-of-school settings depends substantially on how well the visit to an extracurricular learning environment is integrated in class (Glowinski, 2007; Klees & Tillmann, 2015). In consequence, pre- and post-work is essential for extracurricular learning. Streller (2015) proposed implying digital learning for preparing and postprocessing extracurricular learning. The aim of implementing a digital learning environment is being pursued by the working groups for chemistry and physics education at the University of Koblenz-Landau within the joint project Open MINT Labs. According to Snyder, Bolin & Zumwalt (1992) and Blumenfeld, Fishman, Krajcik, Marx & Soloway (2000) implementing an innovation in schools via top-down transfer is rather ineffective and less suitable for long-term changes. Drawing on these findings, our project seeks to build the process of implementation upon the requirements of teachers and schools. This approach is in compliance with Gräsel & Parchmann's (2004) desideratum. Thus, the focus of our study is to anchor a digital innovation concerning successful preparation for and revising of out-of-school learning environments within schools.

Theoretical background

Gräsel (2010) describes four factors of influence concerning the implementation of an innovation in schools: features of the innovation itself, attributes of teachers, characteristics of the individual school, and tokens of the setting. Since our innovation is centred around the virtual labs' hypertext learning material, the innovation's tokens can be addressed directly. As it is our aim to implement the innovation not in one single school but rather in a multitude of educational institutions, being responsive to each schools distinct situation is neither practicable nor expedient. Ultimately, we are therefore addressing three barriers potentially hindering implementation of our innovation in schools, which are also the foundation of Jäger's (2004) wave model regarding transfer of an innovation:

1) learning material: lack of relevance or intelligibility of contents might inhibit student learning
2) scholastic situation: organisational structures may not be suitable for adapting a new concept
3) teacher personality: certain character traits may obstruct willingness to adapt an innovation

The aim of the study is to identify potential barriers and chains of causation in order to facilitate experimental field work with students by pre- and post-work with virtual labs. According to our theoretical framework, applying convincing learning materials is inevitable for shaping effective transfer. Therefore, we decided to create appropriate materials. The virtual labs created by the joint project Open MINT Labs are approved at university level (Roth, Berg, Permesang, Schwingel, Andres & Hornberger, 2015) and share a common structure on the basis of educational methodology according to instructional psychology (Leutner & Wirth, 2018). All newly developed virtual labs for school implementation were constructed in line with Clark and Mayer's (2008) guidelines for multimedia design and the underlying ideas of cognitive flexibility and random access instruction described by Spiro, Feltovich, Jacobsen & Coulson (1992).

The virtual labs in question are constructed considering optimized cognitive load (e.g. Chandler & Sweller, 1991). Extraneous cognitive load can impair learning by claiming limited cognitive resources in order to understand the learning material (Sweller, van Merriënboer & Paas, 1998). We sought to reduce extraneous cognitive load by applying aforementioned principles of multimedia design as well as by a clear surface structure providing valuable depictions and explanations via hyperlinks. Intrinsic cognitive load cannot explicitly be altered as it depends on domain complexity being determined by the quantity of interactive elements (de Jong, 2010). However, our virtual labs have been reviewed by four independent educationalists in order to ensure compliance with the target group's performance. Furthermore, our virtual labs are constructed with the idea of simple-to-complex sequencing in mind in order to facilitate learning of complex subject matters (van Merriënboer, 2003; Pollock, Chandler & Sweller, 2002). Hence, by elaborately handling intrinsic cognitive load and reducing extraneous cognitive load, cognitive capacity for actual learning in the sense of building and interconnecting schemes – also known as germane cognitive load - is freed.

Research questions

1) Which of the posited attributes of barriers hindering the implementation of a digital innovation in schools can be confirmed?
2) Which requirements have to be met by pedagogical concepts for fostering implementation in schools?
3) How can virtual labs foster the emergence of current motivation, flow-experience and cognitive load during pre- and post-work of experimental settings in an outdoor out-ofschool-lab?

Research design and methods

In our study, we investigate two different domains: a) domain of teaching staff and school structures regarding successful implementation of the digital innovation and b) domain of students learning with the innovation. These two domains illustrate the potential barriers underlying our design. Supplementally to the mere analysis of our learning materials we extend our research on how pupils cope with our virtual labs in practice.

Both domains are considered separately since research objectives as well as research methods specifically match each domain. As far as the target group of teachers is concerned, we examine character traits and school structures by means of a repetitive questionnaire-based inquiry and qualitative interviews, resulting in a delphi technique (Kerr & Tindale, 2014). Student behaviour is evaluated by a mixed-methods approach incorporating questionnaires and videography of experimentation settings in order to capture and analyse learning processes. The video material will be evaluated on the basis of an adaption of learning process graphics (e.g. Emden, 2011).

52 science teachers were introduced to our virtual lab concept. After participants were allowed enough time to get to know concept, contents and functionality of our virtual labs, a questionnaire was handed out. The main focus of this questionnaire is to investigate the teachers' mindsets towards digital innovations as well as their openness regarding the implementation of such a concept. The questionnaire consists of four constructs: selfconcept, attitude, ascribed value concerning digital devices and stages of concern. The survey data were validated by structured interviews. Interviewees were mainly teachers, in whose classes we had conducted learning units according to our concept.

During the pilot study students of grades ten to twelve (age 15 to 18) were introduced to the constructed virtual laboratories. Students used these virtual labs to prepare for their field work taking place in the next lesson. At the beginning all students worked on the same lab covering manipulating the equipment to be used later in the experimental setting. Another focus point of this lab is the assessment of measurement data. Afterwards, each student was randomly assigned to a focus group consisting of three to four students. The focus groups each prepared another virtual lab dealing with one of the following parameters to be measured in the field: nitrate, ammonium and chloride concentration, conductivity, flow velocity, pH-value and dissolved oxygen. All virtual lab courses were presented either on laptops or tablet PCs, depending on the school's infrastructure. Following 90 minutes of preparation, all courses participating in the study conducted measurements of a stream in order to assess water quality. All courses worked at the same outdoor laboratory next to a stream, except for one course which had to conduct measurements of prepared water samples due to bad weather conditions. Having completed field work, participants used our virtual lab courses for postprocessing measured data and as a basis on which data quality and factors influencing water quality were discussed. The three parts of the pilot study – preparation, field work and postprocessing – were all carried out within one day to one week. Quantitative data were collected by a questionnaire. Data for the concepts of flow-experience (Rheinberg, Vollmeyer & Engeser, 2003), current motivation (Rheinberg, Vollmeyer & Burns, 2001) and cognitive load (Leppink, Paas, van der Vleuten, van Gog & van Merriënboer, 2013) were gathered during each part of the study by applying three measurement time points. Additionally, system usability was assessed during preparation (Brooke, 1996). Throughout the field work, all focus groups having agreed on videography were filmed.

Collected data and preliminary findings

Regarding teachers, our sample consists of 52 participants (n_{female} = 65%, median age = 40 years), including 33 biology teachers, 25 chemistry teachers and eight physics/ technic teachers by now. The total number of participants striven for is not predefined in this case, as we are planning to interpret data descriptively. Median teaching experience among the teachers was ten years. Perceived value of digital devices is slightly beyond mediocre (*range* = 1-4, *avg* = 2.76, *SD* = 0.70). The scale on self-concept of teachers concerning digital devices shows moderate values (*range* = 1-4, avg = 2.55, *SD* = 0.57). Attitudes towards digital devices are rather high (*range* = 1-5, *avg* = 3.24, *SD* = 0.62). The stages of concern questionnaire revealed a typical non-user profile according to George, Hall & Stiegelbauer (2013). This result was expected as teachers in this early stage of implementation are not actively practicing the digital innovation yet. The immanent demand for further information and tangible pedagogical concepts has been perceived as a anticipation our project group seeks to meet. All scales revealed at least acceptable or satisfying item values, detailed values have been published (Neff, Engl, Kauertz & Risch, in press).

On the side of the students, we gathered 93 complete data sets during our pilot study. Throughout the study we are aiming to achieve a total sample size of 163 pupils in order to statistically compare findings within one group and among three measurements as computed via a power analysis (*f* = 0.1; *power* = 0.8). Flow-experience is mediocre (*range* = 1-7, avg = 3.38, *SD* = 0.89). Current motivation is at a medium level (*range* = 17, *avg* = 3.07, *SD* = 0.81). The likert scale for cognitive load (*range* = 0-10), including subsets of items on intrinsic, extraneous and germane cognitive load, revealed a low level of intrinsic cognitive load (*avg* = 3.39, *SD* = 2.13). Extraneous cognitive load is located at an even lower level (*avg* = 2.94, *SD* = 1.96), from which we can conclude that the learning environment itself does not unnecessarily bind cognitive capacities. Consequently, germane cognitive load is at an intermediate level (*avg* = 5.1, *SD* = 2.18), which means that students managed to apply a useful amount of cognitive capacity on actual learning in the sense of creating and interconnecting formulae (de Jong, 2010). Usability was rated rather high (*range* = 1-5, *avg* = 3.69, *SD* = 0.66) by the participants.

Discussion and revised study design

Due to unsatisfying item parameters, some scales of the questionnaire for teachers had to be reworked. Dropping the items in question did not affect the integrity of the contents as we had previously used multiple scales for identical concepts, resulting in the opportunity to choose the best scale for each concept after the pilot study had ended.

Drawing on observations and experiences from the pilot study among students, the study design was slightly adapted. Video equipment was upgraded in order to improve sound quality and thereby reduce time investment during postproduction. Minor technical flaws could be eliminated by gaining access to a sufficient amount of identical tablet PCs.

All in all, our preliminary findings reveal viable results in the domain of learners and acceptable outcomes on the side of the teachers. Prospectively, we are going to extend our study by increasing the sample. Furthermore, we will seek to optimize teachers' readiness for and learners' benefit from the implementation of our innovation by adjusting pedagogical concepts accompanying the transfers as well as by teacher training.

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Fostering internal mental model-construction through Augmented-Reality while learning Organic Chemistry

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Introduction

One of the major problems in chemistry education for students is to be faced with lots of different types of representations (Treagust, 2003; Gilbert, 2007; Rau, 2017). Especially novices can easily be overwhelmed by the mental translation of two-dimensional visualizations into three-dimensional mental models. Against the background of cognitive theories of learning, this translation process sets high demands on learners' working memory which has limited capacity (Sweller et al., 2011). Considering the cognitive load theory, three types of cognitive load (intrinsic load, extraneous load and germane load) have to be processed within this limitation. Especially for novices in a specific domain the mental translation of representations comes along with high levels of intrinsic load. Instructors should therefore look for ways to present information in a way that minimizes unnecessary extraneous load by designing appropriate learning materials.

A promising approach to address this problem is the integration of Augmented Reality (AR) technology in chemistry instruction. Based on Azuma (1997) AR allows to embed virtual three-dimensional objects via smartphones or tablets in a real-world environment. By using a so-called tracker-based AR approach it is possible to integrate three-dimensional virtual models on or next to a two-dimensional image (tracker). From a cognitive psychology perspective there is reason to assume, that this can support students in their translation process and hence reduces the amount of extraneous load. AR also provides the opportunity to interact with these objects in real time, to rotate them or to zoom in and out (Azuma, 1997).

Although there is evidence to assume that AR supported learning materials might be capable of reducing students' extraneous cognitive load there is also reason to assume, that they lead to unintended high load levels. Obviously, the app to be developed should be distinguished by a good usability for avoiding the increase of extraneous load. Therefore, the usability is one of the core parameters to measure the quality of the app.
The effects of AR-based chemistry-learning on learning gains as well as affective and cognitive variables will be investigated in the context of this PhD- researchprojects.

Theoretical Background

In chemistry, students are faced with lots of different types of external representations, like sum formula, wedge-and-dash-structures or ball-and-stick models (Treagust, 2003; Gilbert, 2007; Rau, 2017). All these types of representations depict information on different levels of abstraction. For novices it is not easy to extract relevant information and to integrate them into their learning process meaningfully. Especially the processing of three-dimensional information demands sophisticated spatial abilities, which can easily be overwhelming for novices in a specific domain (Oliver-Hojo & Sloan, 2014).

All parts of the elaboration take place in the working memory. Concerning the *Dual Coding Theory* (Paivio, 1990) verbal and pictorial representations are perceived and processed separately in working memory. For constructing an internal mental model, as the result of a succeeded elaboration, the information of both representations-types get finally matched together. Obviously, the matching can get more fluently, if the different representations-types are contentwise consistent. Thus, from a cognitive psychology perspective, the instructional design of learning materials is key for the successful elaboration of a learning subject. Instructors should focus to minimize the amount of extraneous load by designing appropriate learning materials in order to maximize the possible amount of germane load.

The wide spread use of hand-held devices like smartphones or tablets provide new possibilities to support learners and instructors. One of the possibilities is the technology of Augmented Reality. Research concerning the benefits of AR in educational contexts shows positive effects on affective variables, like motivation for learning and gaining long term interests (Chen et al., 2011; Martin et al., 2012). Considering cognitive aspects, short and long term learning success was supported (Blanco-Fernández et al., 2014; Ibánez & Delgadro-Kloos, 2018). Another potential of AR is the reduction of cognitive load during learning (Lindgen & Moshell, 2011; Ibánez & Kloos, 2018).

Based on the existing research results of Augmented Reality as a powerful technology for providing multiple representations, this research project addresses the following research questions:

1. *Does the use of Augmented Reality supports learning of organic chemistry in comparison to traditional text and picture based learning?*
2. *Is the estimated effect addressed in research question 1 moderated by the ability of mental spatial rotation?*

3. *Does the use of Augmented Reality when learning organic chemistry cause lower cognitive load in comparison to traditional text and picture based learning?*
4. *Does the use of Augmented Reality when learning organic chemistry cause higher amounts of situational interest in comparison to traditional text and picture based learning?*

Methods and Design

To answer these questions, i conduct two quasi-experiments. A first experiment takes place in the winter semester 2019 / 2020 in a pre-post design. The experiment consists of four sessions, 90 minutes each, which are integrated into the lecture Organic Chemistry II for chemistry-students at a German university. 61 Participants (38 male, 23 female) take part at this first experiment. The average age of these students is 21,43 years (*SD* = 2,784) and most of them join this lecture in the third semester of their study program.

In the first session the students´ knowledge about stereochemistry, carbonyl-reactions and pericyclic-reactions is measured by a pre-test as well as their ability of mental spatial rotation and their cognitive performance in general.

In three different lecture-sessions spread over the semester i perform interventions concerning stereochemistry, carbonyl-reactions and pericyclic-reactions in an experimental-control group design. The students are assigned to the groups depending on their individual scores in the pre-test to ensure comparability.
Each intervention lasts about 60 minutes. During this time, the participants of both groups work individually on paper-based learning materials, which consist of text and pictures. The learning materials are self-developed, based on common literature of organic chemistry (Schmuck, 2018) and in consultation with the lecture´s professor.

Additionally to the learning material, the experimental group uses the self-developed application called *ARC* on an Apple *iPad* to trigger the markerbased AR. An AR-marker is a picture in the learning material, which is linked with a corresponding three-dimensional model or animation in the App. For example, the learning material for stereochemistry contains 15 three-dimensional models, which can be rotated by finger-movement on the screen and nine three-dimensional animations.

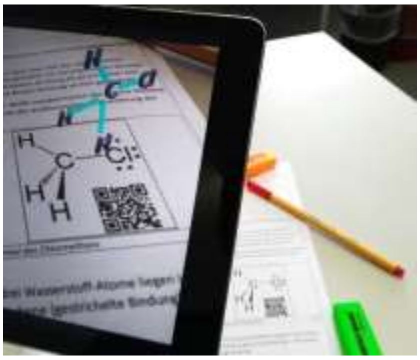

Figure 1: The App „Augmented Reality Chemistry" in use"

After each intervention-session the participants work on a post-test for about 30 minutes. Items from the topic of the intervention session before (e.g. stereochemistry) will measure the students´ specific content knowledge right after the intervention. Additionally, the participants have to rate their perceived cognitive load during the elaboration of the learning-material (with AR respectively without AR) using a questionnaire adapted by Klepsch et al. (2017) on a six-point LikertScale. They are also asked to rate the App-usability on the so-called system usability scale (SUS) by Brooke (1996), which contains ten five-point Likert scaled items. The items of the SUS can be used to calculate a usability score, which can be interpreted on a scale from 0 (bad) to 100 (excellent). Also 18 Items are included in the post-test to measure affective variables like situational interest and motivation on a six-point Likert-Scale (adapted by Rheinberg et al., 2001).

The design of the experiment allows to compare the students´ knowledge of the three topics before and after each intervention. It´s also possible to take a longitudinal view on the process over time of variables like the cognitive load or the situational interest. Also the experimental- and the control group are comparable with each other at each lecture-session to determine the effects of using AR.

One year later in winter semester 2020 / 2021 i intend to repeat the experiment with a new comparable group of students and also to expand the design. It is estimated, that the experimental group will reach higher post-test scores though the AR-use, which should be investigated in detail. For this second experiment a new intervention group will be added, which will use computer-based three-dimensional models and animations in addition to the paper-based learning material. The reason is, that i want to investigate, if the estimated higher results of the experimental group are based on the AR-features itself or are only based on the presentation of the three-dimensional content. In case of the AR-use, the two- and three-dimensional representations are presented near each other, while in case of computer-based models the three-dimensional representations can only be seen on a different screen, which can cause a split-attention-effect.

Preliminary results

Before setting up the described research-design, a pre-study with 22 participants at a German university was conducted to investigate the usability of the AR, especially taking the cognitive load and the usability into account. The participants were undergraduate students, who were enrolled in a chemistry program, but did not participated in lectures about organic chemistry yet.

I ensured to test 11 male students, as well as 11 female students to provide an equal gender proportion. During a working phase of about 60 minutes the students worked on AR supported learning tasks on nucleophilic substitution reactions (S_N2). The instructional design consists of common text- and picture representations and AR based visualizations and animations. The AR provides 15 three-dimensional virtual and rotatable molecular formulas and nine three-dimensional animations of several parts of the S_N2-reaction. Afterwards the participants rated their perceived cognitive load using a questionnaire adapted by Klepsch et al. (2017) on a six-point Likert-Scale. They also rated the app-usability on the so-called system usability scale (SUS) by Brooke (1996), which contains ten five-point Likert scaled items.

Perceived cognitive load

Immediately after the intervention, the students were asked to rate their perceived intrinsic-, extraneous- and germane cognitive load (see the means in Figure 2). 6

The participants rated the intrinsic load of the learning subject S_N2-reaction with an average score of *M* = 3.29 (*SD* = 1.26). The average rating for extraneous load is *M* = 2.05 (*SD* = 0.90). The mean germane load is *M* = 5.23 (*SD* = 0.54). Comparing the extraneous and the germane load indicates a significant difference 3 (*t*(22) = -11.55, *p* < .001). Also the comparison of germane load and intrinsic load shows a significant difference (*t*(22) = -5.72, *p* < .001).

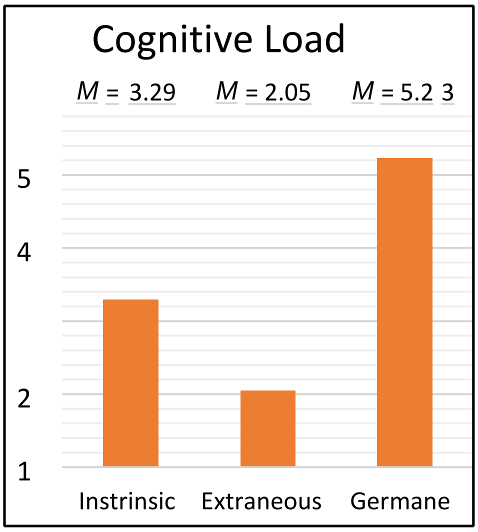

Figure 2: Perceived cognitive load

Usability

As mentioned above, the SUS (Brooke, 1996) was used to calculate a usability score for each student. The mean usability score over all participants is *M* = 84.89 (*SD* = 17.91) on a scale between 0 (worst imaginable) to 100 (best imaginable). In relation to Brooke (1996), the app usability can be interpreted as nearly *excellent.*

18 of the 22 participants rated the App-usability as *best imaginable* or *excellent* and three students voted for *good* or *fair* usability. Only one participant perceived the App-usability as *worst imaginable*.

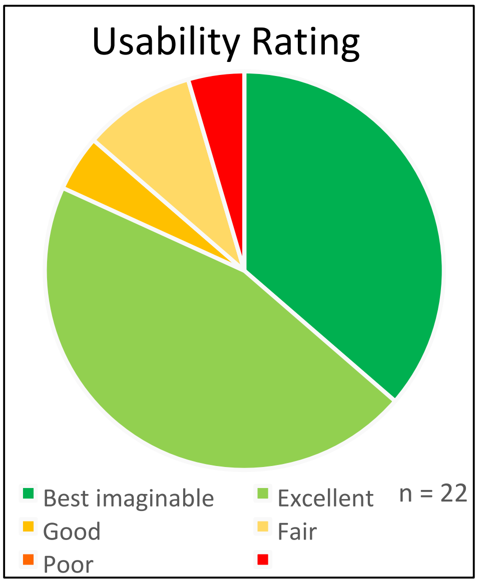

Figure 3: Usability Rating

Discussion

The results of this pre-study suggest, that it is possible to offer an Augmented Reality based instructional design, which supports novices in learning organic chem- istry. The most important argument therefore is, that the students rated the perceived extraneous load as pretty low (*M* = 2.05, *SD* = .90). This result is supported by the usability rating. The overall usability score confirms nearly an excellent usability. Both results certify, that the content related interconnection of the paper-based text- and picture learning material with the functionalities of the app works well. Compared to the levels of intrinsic and germane load, extraneous load is quite low. The low extraneous load indicates that the learners can invest lots of their cognitive capacity for elaborating the concept itself (described by the high amounts of germane load) and are not distracted by a severe instructional design or hindering AR-use.

Of course, it has to be kept in mind, that this pre-study was conducted with only 22 participants. Therefore, the results have to be interpreted carefully. Nevertheless, they give a first indication about the potentials of AR to support learning in organic chemistry.

In future I want to validate the indicated effects of learning gains in the both described quantitative experiments. I would appreciate to discuss my research project during the ESERA Summer School 2020.

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Studying Identity and Organizational Environment:Manifestations in Postsecondary STEM Instructional Practices

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Abstract

As the calls for evidence-based instructional practices in college STEM increase, it becomes essential to examine postsecondary instructors' teaching practices and factors affecting them. This study aims to investigate; 1) in what ways postsecondary STEM instructors' identities are manifested in their practices, 2) how the organizational climate affects their teaching practices, and 3) how the construct of identity, context and practices related to each other. To provide empirical evidence underlying these questions, a mixed method research design will be employed. Theoretical underpinnings, the rationale for the study, research design and limitations are discussed. However, a discussion of data and preliminary findings is not applicable because data collection has not started yet.

Introduction

As many educational and governmental bodies call for student-centered teaching strategies in college science, technology, engineering, and mathematics (STEM) education (e.g., American Association for the Advancement of Science (AAAS), 2013; Freeman et al., 2014; Wieman, 2014), it becomes essential to understand postsecondary instructors' teaching practices and the factors influencing the implementation of evidence-based instructional practices (EBIPs). This mixed method study, a work-in-progress, aims to examine STEM faculty's teaching practices and how their identities and the institutional environment relate to instruction. In the following paragraphs, I will briefly lay out the rationale and significance of this study. Then, I will present main theoretical frameworks underlying this proposal and research questions. Following that, I will outline the research design including the context, data collection and discussion of analysis, and limitations. Since I have not started to collect data yet, planned in Spring 2020, I will not be able to present any preliminary findings. If I am accepted to ESERA Summer School, I will have the data to present and discuss with my peers and mentors.

Even though studies highlight the need for empirically validated instructional methods (i.e., Freeman et al., 2007; Freeman et al., 2014; Snyder et al., 2016), scholars reported that STEM faculty maintains the use of traditional teaching practices (i.e., Bathgate et al., 2019; Stains et al., 2018; Walter et al., 2016; Williams et al., 2015). Factors associated with the limited adoption of EBIPs include teachers' beliefs, self-efficacy, time limitation, structural and cultural barriers, social and departmental norms, student resistance, and lack of pedagogical training (i.e. AAU Report, 2017; Andrews et al., 2016; Bathgate et al., 2019; Birt et al., 2019; Robert & Carlsen, 2017). However, relatively little research has investigated postsecondary instructors' identity, the organizational climate for instructional improvement and how these elements relate to teaching practices.

Walter et al. (2014) stated that it is essential to understand the organizational climate for instructional improvement to study the effect of reform initiatives. An investigation of the institutional environment and instructional practices can be useful to identify individual, departmental, and institutional needs, and to document the results of professional learning activities and to plan and evaluate future reform actions (AAAS, 2013; Walter et al., 2014). As a result, it is important for researchers to provide empirical evidence demonstrating the characteristics of STEM teaching practices at different institutional settings.

The current literature on teacher identity within science education field shows the use of teacher identity as a way to study teacher learning, decision-making, and development (e.g., Avraamidou, 2014; Luehman, 2007). However, there is less examination of teacher identity among postsecondary STEM instructors. Brownell and Tanner (2012) asserted that the culture of science can complicate the development of identity for college teachers. Scholars argued that the development of teacher identity is affected by training as a researcher but not a college teacher, being afraid to come out as teachers, and lack of recognition by community (e.g. Brownell & Tanner, 2012; Carlone & Johnson, 2007; Connolly et al., 2016). Research also demonstrated that independent teaching experience, teaching professional development and teaching mentors contributed to teaching identities of life sciences doctoral students (Lane et al., 2019). Thus, in addition to studying the impact of context, an examination of postsecondary STEM instructors' teaching practices in reference to their identities can help us better understand their professional needs and identify ways to promote EBIPs in college STEM classrooms.

Review of the literature

Effective and efficient STEM education is critical to cultivate a scientifically literate citizenry, to attract diverse group of students, and to enhance workforce readiness (e.g. AAAS, 2011; NRC, 2000; Romine et al., 2017). Learning theories, empirical studies about how people learn, and assessment of outcomes in STEM classrooms highlight the need for improved teaching methods to support learning and student persistence (i.e., Freeman et al., 2007; Freeman et al., 2014; Snyder et al., 2016). Nonetheless, scholars reported that STEM faculty maintains the use of traditional teaching practices even though many reform efforts recommend empirically validated instructional strategies (i.e., Bathgate et al., 2019; Stains et al., 2018; Walter et al., 2016; Williams et al., 2015). Researchers also stated that reform efforts to improve STEM teaching reached modest success (Stains et al., 2018; Walter et al., 2014; Williams et al., 2015).

Substantial research articulated that initiatives to improve STEM teaching and implementation of EBIPs are affected by contextual factors such as institutional values, organizational support, rewards and resources (e.g., Beach et al., 2012; Birt et al., 2019; Lazerson et al., 2000) Bathgate et al. (2019) found that STEM faculty reported greater implementation of EBIPs when they perceive more social, personal, and resource supports. Kezar (2011) suggested that scholars need to consider '*creating professional dialogues and networks and examining the infrastructure of support*' to build successful reform initiatives. Thus, it is significant to examine the relationship between postsecondary STEM teaching practices and different institutional settings.

Considering that STEM classes still abound in traditional teaching practices (Stains et al., 2018), the evaluation of the issue holistically, including the personal factors such as identity in addition to institutional environment, is essential. Recent studies focused on investigating the elements such as faculty's self-efficacy, their beliefs about teaching and learning, and intrinsic goals influencing their teaching practices (i.e., Ferrare et al., 2019; Gibbons et al., 2018; Lund & Stains, 2015; Robert & Carlson, 2017). However, there exists a significant need for empirical evidence describing postsecondary instructors' identity and how their identities associated with enacted instructional practices.

According to the conceptualization in the literature, teacher identity is '*social, multidimensional, tentative, and always in the process of formation and reformation*.' (Avraamidou, 2014a). Identity includes view of the self as a teacher, collegiality, recognition by others, subject matter knowledge, prior experiences, beliefs about science teaching and learning, and race, gender, and ethnicity. Studies within the science education literature revealed the relationship between the implementation of reform-based materials and teacher's professional identities (i.e., Forbes & Davis, 2008; Pedretti et al., 2008). Moreover, Avraamidou (2014b) studied how experiences with science and teaching in different contexts affected the development of science teachers' identity. However, there exists a significant need for empirical evidence demonstrating the link between STEM faculty's identities and their teaching practices.

Although there is less examination of teacher identity among postsecondary STEM instructors, researchers tried to understand how professional teacher identity affected by several factors. For example, Thiry and their colleagues (2007) found that a group of underrepresented graduate students in STEM felt to focus more on research over teaching because of the pressure by the faculty and their peers. Carlone and Johnson (2007) claimed that professional identity might be deteriorated due to a lack of recognition by the community. Another study showed that women in STEM fields were not supported by their supervisors when they wanted to pursue teaching-related careers, and that restrained their identities (Szelényi et al., 2016). On the other hand, Connolly et al. (2016) showed that participation in teaching professional development helped STEM doctoral students to promote their competence as teachers and a sense of community with their peers. Moreover, Lane et al. (2019) demonstrated that independent teaching experience, teaching professional development, and teaching mentors contributed to teaching identities of life sciences, doctoral students.

Brownell and Tanner (2012) asserted that the culture of science could complicate the development of identity as college teachers. They also said that college instructors without professional teacher identity might be less willing to forge their teaching practices. They described three tensions between professional teacher identity and implementation of EBIPs; 1) training as a researcher but not a college teacher, 2) being afraid to come out as teachers, and 3) the professional culture of science which favors research over teaching. Therefore, this study aims to deepen our understanding of the link between identity, context and practices. The tentative research questions are;

1. In what ways postsecondary STEM instructors' identities are manifested in their teaching practices?
2. How does the organizational climate affect their practices?
    a. How does the implementation of EBIPs change within different departments at different types institutions?
3. How do these three constructs -identity, context, practice, relate to each other?

Research Design

To provide empirical evidence underlying the research questions, this study will employ a mixed-method research design. A mixed-method design could integrate the strengths of qualitative and quantitative methods for better understanding the focus of this study. The majority of studies on teacher identity rely on qualitative methods to provide detailed information through a small number of participants (Avraamidou, 2014a). In contrast, current literature on STEM faculty's teaching practices provides us with empirical findings through quantitative design (Williams et al., 2015). Therefore, there is a need for studies investigating the link between identity, context, and teaching practices through both qualitative and quantitative measures with a large number of participants. For instance, the researcher could answer the questions through a qualitative approach and ensure the replication of the study through quantitative measures (Castro et al., 2010). Collecting data through mixed-method design could also let the researcher triangulate data effectively (Ortiz & Greene, 2007).

Context

Woodbury and Gess-Newsome (2002) asserted that researchers need to examine the structure and cultural context of the institution to explain the reason for the limited success of reform initiatives to change STEM education. However, the majority of researchers focused on STEM instructors at research-intensive, doctoral-granting institutions to explore teaching practices and factors associated with faculty's choices (Ferrare, 2019; Stains et al., 2018). Therefore, I aim to collect data from six different institutions in Northeast New York including two private research-intensive colleges, two public universities, and two community colleges. Despite the increasing body of literature on the teaching practices of postsecondary STEM instructors, insufficient research examines the comparison of institutions regarding the faculty's instructional practices. This study could help us to address the gap in the literature. Measuring the instructional practices of university instructors can serve as baseline data for individual instructors, departments, institutions, researchers to plan faculty development, and policymakers to enact change initiatives.

Data collection

Data will be collected from purposefully selected participants (Creswell, 2012) who are STEM instructors at different institutions in Northeast New York. After receiving Institutional Review Board (IRB) approval at Syracuse University, online surveys will be sent to participants via emails. The survey will include a question about participating in interviews at the end. I plan to start the recruitment process and data collection in March 2020.

Data collection tools include; (1) Postsecondary Instructional Practices Survey (PIPS) (Walter et al., 2016), (2) Survey of Climate for Instructional Improvement (SCII) (Walter et al., 2014), (3) Faculty Instructional Barriers and Identity Survey (FIBIS) (Sturtevant & Wheeler, 2019), and (4) semi-structured interviews focusing on identity, beliefs about teaching and learning. Although it looks like an exhaustive list, the combination of these instruments will provide triangulation of the data. PIPS is designed to collect data from all postsecondary faculty's teaching in terms of instructor-student, student-student, and content-student interactions and the use of formative and summative assessment. The instrument also involves demographic questions about instructors' background. SCII measures organizational environment including leadership, collegiality, resources, respect for teaching, and organizational support. I plan to use these two instruments in their entirety. FIBIS aims to assess faculty professional identity, satisfaction with the use of EBIPs and barriers to instructional development. Identity section of this instrument addresses faculty's identity associated with institutional research and teaching community. Evidence collected through this instrument could provide opportunity for data triangulation. Finally, faculty members will be invited to participate semi-structured interviews addressing identity. Interview protocol will focus on how instructors view themselves, how they are recognized by their colleagues, and how their experience, race and gender from their identities as teachers of STEM. As a result of these measures, I am particularly excited to see the intersectionality of professional teacher and researcher identities and how they are affected by the organizational climate.

Discussion of Analysis

Data analysis will include interpretive qualitative analysis (Bogdan & Biklen, 2007) and quantitative analysis (Keith, 2015; Leech et al., 2015). Semi-structured interviews will be audio recorded and transcribed. The transcriptions will be analyzed based on Yin's nonlinear five analytic phases; (1) compiling, (2) disassembling, (3) reassembling, (4) interpreting, and (5) concluding (Yin, 2011). These stages include reading and re-reading the transcripts, coding, categorizing the codes and continuously looking for patterns. To make the procedure more efficient and rigorous, I will exercise certain precautions such as checking and rechecking the accuracy of the data, making comparison, looking for negative instances, and continually posing questions about the data and to myself. Qualitative analysis will answer my questions about faculty identity.

Quantitative analysis will include multiple regression analysis, multilevel modeling, and k-means clustering. In order to understand the link between the context and teaching practices, multiple regression analysis will be conducted. It is appropriate to show the association between variables. The relationships between subcategories in the instruments could help to develop regression models. Moreover, I will conduct multilevel modeling because I will deal with nested data including individual instructor level, department level and institutional level. Multilevel linear modeling can help me to treat instructors as nested within particular departments and to examine the role of institution or classroom-level data, gender, class size or type of university (Leech et al., 2015). I plan to use either SPSS or R to conduct quantitative analyses. Finally, to understand the link between identity, context, and teaching practice, I plan to conduct k-means clustering through MATLAB. K-means method algorithm will allow me to group participants to nearest neighbor clusters. I hope to have space to discuss these models and learn from different perspectives in the summer school.

Limitations

The most significant limitation to this study would be is that I do not plan to observe participant instructors while using evidence-based instructional strategies. In order to maintain data triangulation, supporting survey and interview data with classroom observation would be beneficial. However, that kind of study would require a longer time to complete the study for me and more commitment for the participants. This study will be limited by the fact that I aim to collect data from certain type of institutions at a particular location. It will restrict the ability to ensure external validity. Finally, construct validity could be addressed through confirmatory and exploratory factor analysis.

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Physics specific refinement of a learning theory

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Abstract

PISA (Schleicher, 2019) and the IQB Education Trend (Stanat et al., 2019) indicate a deterioration in scientific competences for German students. To counter this trend, effective teaching models are required. The Basis Model Theory of Oser and colleagues (Oser & Baeriswyl, 2001; Oser & Patry, 1990) provides a promising structuring tool. In order to apply the Basis Model Theory subject-specifically in physics, further development is needed, which also discusses the implementation of the theory at the quality level (cf. Geller, 2015). In order to map this further development in a ranking system, the first step of the study was to analyse N=126 lesson plans and, based on this, to develop initial criteria. In the further course of the study, these criteria will be generalized and empirically tested.

Focus of the study

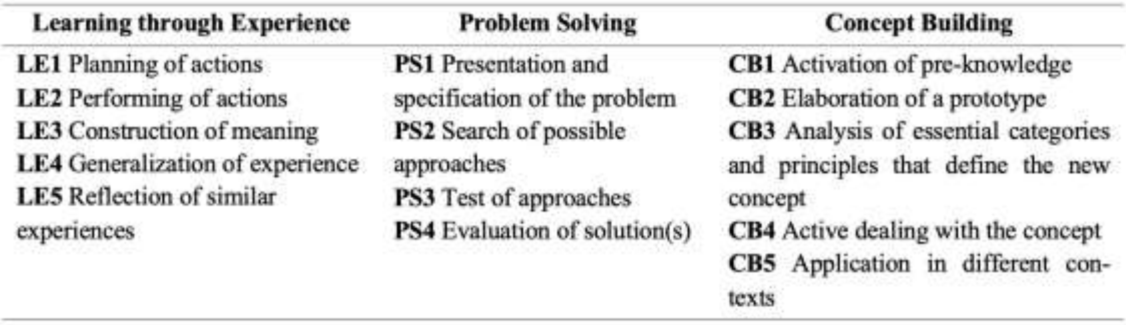
The results of the current PISA study (Schleicher, 2019) show a deterioration in the scientific competences of students in OECD countries. The IQB Education Trend 2018 (Stanat et al., 2019) also discovers a similar trend at German secondary schools for the subject of physics. According to Köller (2020), this national and international trend can partly be attributed to more heterogeneous classes. In order to enable particularly lowerachieving students to participate in science lessons teachers must rely increasingly on immanent instructional theories that focus on the learning process of the learners and support the disadvantaged groups in particular.

In this context, the Basis Model Theory (BMT) by Oser and colleagues (Oser & Baeriswyl, 2001; Oser & Patry, 1990) is to be mentioned, which, as a cross-curricular theory, describes teaching at the deep structure level and is strongly oriented towards the learning process. Initial studies attribute good effects on learning success to the use of the BMT in physics lessons for concept building, which is particularly beneficial for lowerachieving students (Maurer, 2016). Thus, the BMT would have the potential to address the challenges of increasingly heterogeneous classes. But in order to use this potential properly, the BMT for concept building in physics needs further subject-specific development, which defines quality criteria that are prognostic for learning success (cf. Geller, 2015). The aim of the study therefore is to elaborate these subject-specific criteria and integrate them into the existing model.

Review of Relevant Literature

To address the implications of national and international assessments (cf. Schleicher, 2019; Stanat et al., 2019), learning-effective teaching is a requirement. According to authors of the IQB study (Henschel et al., 2019) there are several characteristics of good teaching - one of them is structuring. This turns out to be particularly important for the learning success (Racoczy et al., 2010; Maurer, 2016). It can be implemented on the level of visual structure as well as deep structure. However, according to Kunter and Trautwein (2013), the second is more relevant as it is aiming at the learning processes of the students. In this context, the Basis Model Theory by Oser and colleagues (Oser & Baeriswyl, 2001; Oser & Patry, 1990) provides a promising model that describes teaching on the deep structure level. Within that theory, basis-models can be understood as “learning scripts” (Oser & Baeriswyl, 2001, p. 1045) which consist of chains of consecutive, functional elements. In order to provide a substantial learning process, teachers must select a basismodel that reflects the predetermined teaching goal and follow the predefined chain of functional steps on the deep structure level (see Table 1). Teachers retain complete autonomy on how they organize teaching on the visual structure level. In that way, the basismodels focus only on the necessary learning structure.

Table 1 *– Sequence of functional elements for LE, PS & CB (adapted table after Oser & Baeriswyl (2001) and Geller et al. (2014, p. 83))*



Learning through Experience	**Problem Solving**	**Concept Building**
LE1 Planning of actions	**PS1** Presentation and specification of the problem	**CB1** Activation of pre-knowledge
LE2 Performing of actions	**PS2** Search of possible approaches	**CB2** Elaboration of a prototype
LE3 Construction of meaning	**PS3** Test of approaches	**CB3** Analysis of essential categories and principles that define the new concept
LE4 Generalization of experience	**PS4** Evaluation of solution(s)	**CB4** Active dealing with the concept
LE5 Reflection of similar experiences		**CB5** Application in different contexts

Within physics teaching, it was observed that only three basis-models are mainly used: Learning through experience, problem solving and concept building (Trendel et al., 2007; Reyer, 2004). Concept building in particular is central to learning new theories in the physics classroom. However, these studies also show that there are deficiencies in the implementation of the BMT in German physics teaching. For example, due to its inquiring character, elaboration within the basis-model concept building takes up time resources that are at the expense of application (Trendel et al., 2007; Geller, 2015). At the same time, Maurer (2016) emphasizes the positive effects of this basis-model on the learning success, particularly of lower-achieving students, under laboratory conditions. This conflict between the deficiencies in the implementation of the basis-model concept building in physics teaching and the actual positive effect on learning success leads to the question of how the quality of the implementation of this basis-model can be achieved for physics teaching. Geller (2015, p. 136f.) specifically calls for the subject-specific development of the BMT, including quality criteria that answer questions such as "How well does the prototype represent the concept". In the publications of Oser and colleagues (1990; 2001), only indirect statements on the transfer of the deep structure level to the visual structure level can be found. The aim of the study therefore is to explore the model and the quality criteria, that underlie the implementation of the BMT (see Figure 1). An initial approach to quality grading is given in Wackermann (2008) which could serve as starting point.

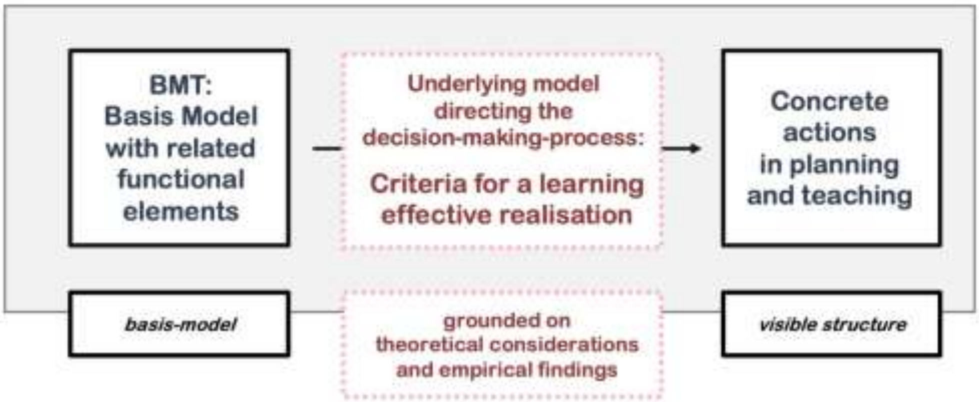


Figure 1 *- Underlying model for realisation of the BMT*

Research Questions

In order to explore the underlying model that accompanies the BMT within physics teaching we pose the following question:

Which criteria does the underlying model for concept building follow to translate the functional elements into concrete teaching actions in physics?

This leading research question is divided into three sub-questions. The first sub-question is based on an inductive approach, in order to explore the general structure of the argumentation in a concrete teaching unit. The following question then aim at generalisation to other lesson content. Finally, the last question addresses the validity of the quality criteria with regard to learning gains.

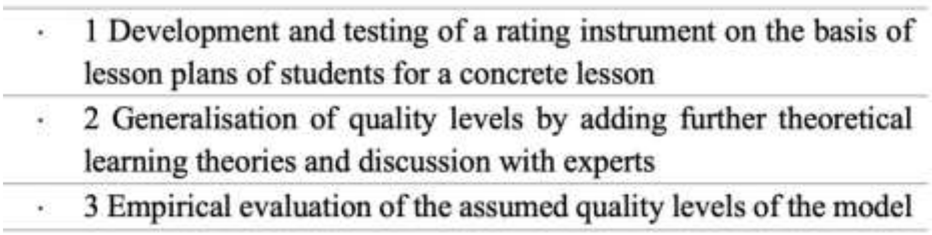
RQ1: To what extent is it possible to develop a quality grading model for a specific physics teaching unit on the basis-model concept building and which concrete quality levels can be seen in this concrete unit?
RQ2: To what extent can this quality grading model be generalized for the basis-model concept building?
RQ3: Are the defined quality levels of the model significant for learning success?

Design and methods

The design of the study has three stages. In the first stage, standardised lesson plans are examined with the aim of designing a rating instrument that reflects the quality levels of the individual functional elements. These quality levels are developed inductively from the material. Thus the rating instrument is in the first instance exemplary.

The next stage is devoted to the generalization of the quality grading model underlying the rating instrument. First, the underlying theoretical argumentation model is to be mapped using learning theories in the context of concept building. The theoretically elaborated, general gradation will then be discussed with experts. In the last stage, the defined gradation will be empirically tested (see Table 2).

Table 2 *– Study Design*



- 1 Development and testing of a rating instrument on the basis of lesson plans of students for a concrete lesson
- 2 Generalisation of quality levels by adding further theoretical learning theories and discussion with experts
- 3 Empirical evaluation of the assumed quality levels of the model

Stage 1: The study uses lesson plans of students that were collected in the course of the project ProfileP+ (Vogelsang et al., 2019). A standardized planning instrument (Schröder et al., 2019) was applied, in which students were asked to plan a physics lesson on the 3rd Newtonian Law. In the pen-and-paper test with a 60-minute test time, the tabular course plan of the fictitious lesson as well as other aspects such as experiments, tasks and blackboard picture had to be recorded by the participants. The test was conducted at four different locations in Germany (Aachen, Bremen, Paderborn, Potsdam) before and after the practical semester. A total of 63 pre-post pairs, i.e. 126 lesson plans, are available.

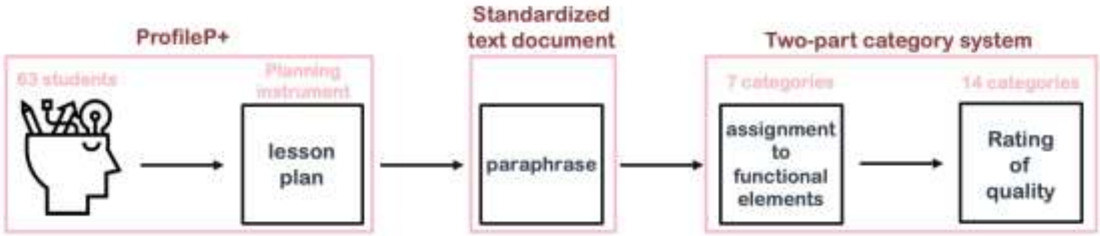


Figure 2 - *Stage 1: Content Analysis*

In a first step of the analysis, the students' lesson plans were paraphrased and complemented with other information from the planning test (e.g. experiments or tasks), so that standardized text documents were present for the subsequent content analysis. Based on this, the two-part rating instrument was then developed (see Figure 2). Part A contains categories that describe the allocation to the individual functional elements of the basismodel concept building. This part of the category system follows the guidelines of deductive content analysis (Mayring, 2010) and was developed following Krabbe, Zander & Fischer (2015) and Wackermann (2008). Part B of the rating instrument results from the inductive content analysis (Mayring, 2010) of the occurring forms and levels of the individual functional elements given by the students' plans. These were hierarchized by the consideration of the BMT (Oser & Baeriswyl, 2001; Oser & Patry, 1990) (see Figure 3).

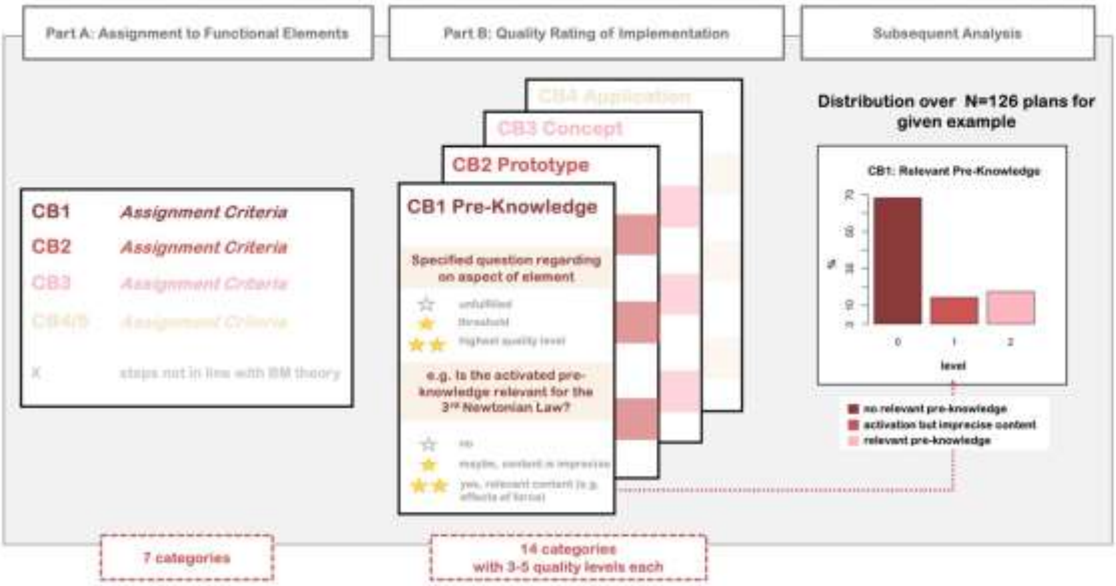


Figure 3 - Two-stage category system

The 126 lesson plans were coded by 2 raters using the developed rating instrument. For validating the category system, an interview study with N=11 students was conducted. The participants completed the planning instrument in the same way as students in the main study (Schröder et al., 2019). Afterwards they were asked to elaborate their plannings orally. These verbal statements were then compared to the interpretations the raters made based on the category system.

Stage 2: The underlying argumentation model of the quality levels is generalized by including further learning theories. The questions raised by Geller (2015), e.g. "what makes a good prototype", are to be answered here in general terms and incorporated into a model. This generalized model for the quality grading of the functional elements within the basismodel concept building will then be discussed with experts from physics education aiming at achieving consensus and establishing valuable criteria. In addition, core aspects to be tested in step 3 will be identified and recorded.

Stage 3: In order to empirically test the identified core aspects with regard to their effect on learning success, learning videos will be produced. We plan to test the learning videos with students as an experimental laboratory study. The videos will be structured according to the basis-model concept building, but will differ within their quality level of their functional elements. Otherwise they will be constructed to meet the criteria of good explanatory videos (Kulgemeyer, 2018).

Indication of nature and extent of data

A total of 126 lesson plannings from 63 master students (before and after their internship) from four different locations in Germany (Aachen, Bremen, Paderborn, Potsdam) form the basis of the first stage. All 126 lesson plannings have been paraphrased and then analysed to develop the two-stage category system. The category system was applied by two raters and cognitively validated through an interview study with 11 students.

Preliminary findings

Based on the analysis of the 126 lesson plans, a two-stage category system was developed. The second stage of the rating instrument, which maps the quality levels of the functional elements, contains 14 categories, each with three to five quality levels. Figure 4 shows exemplary the essential categories for the functional elements “pre-knowledge”, “prototype” and “concept”.

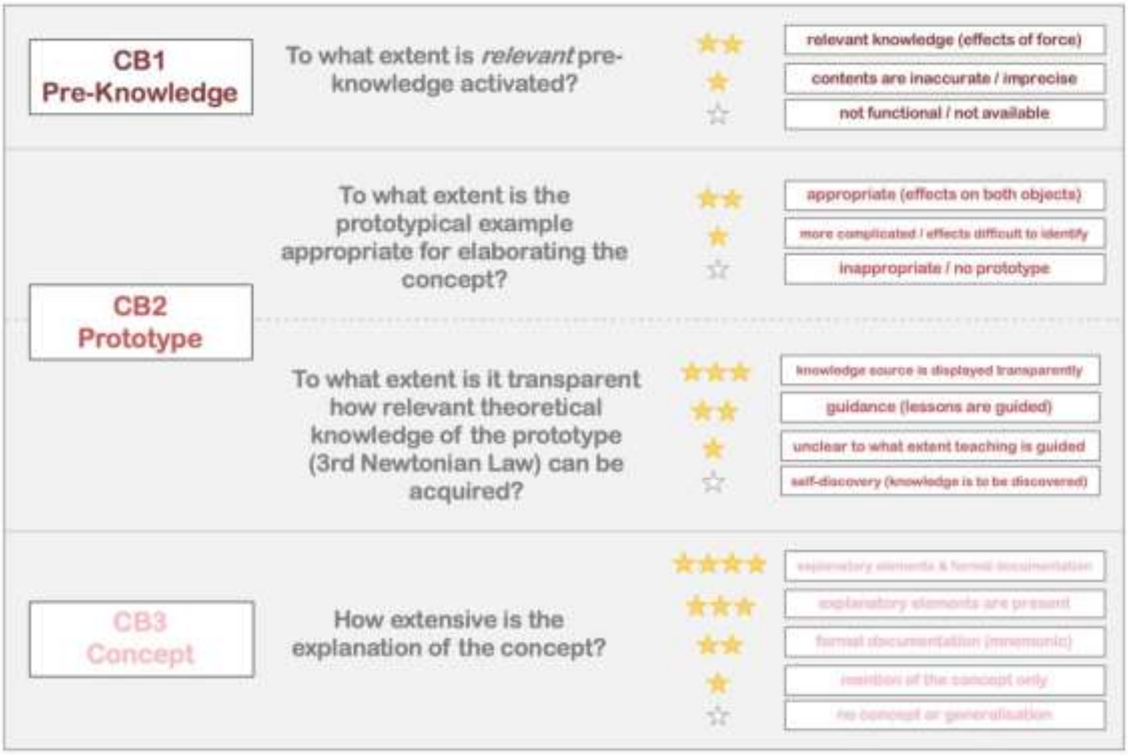


Figure 4 - Extract from category system with the individual quality levels (simplified)

The category system provides a wide variety of quality levels, some of which do not reach the threshold needed to learn the concept. It can be assumed that the learning process of the potential school students is impaired by inferior quality levels (cf. Geller et al., 2014). In order to have a model for learning effective teaching that also supports lower-performing learners in physics lessons, it is necessary to develop generally valid criteria for the basis-model concept building. In this context, the developed category system can be seen as the basis for a subsequent generalisation.

Discussion of analysis

A preliminary interrater agreement ranging from 69% to 95% for the different categories as well as the results of the interview study provide strong indications on the validity of the category system. At the moment, however, we are still in need of external confirmation of the order of the gradations within the category system. Both, the final examination of the interrater agreement and the external confirmation by experts, will provide evidence as to what extent the emerging categories are valid.

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Authoring a science identity: A case study with Afro-Caribbean students in the Netherlands

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Prof. dr. Lucy Avraamidou, Supervisor

Rationale for Study

The ways in which someone is positioned in the world of science or the process of becoming (or not) a science person is conceptualised through the construct of science identity. Science identity is simply defined as having three components: recognition, competence and performance (Carlone & Johnson 2007). This study aims to explore the ways in which a group of purposefully selected students belonging in the Afro-Caribbean community come to form, negotiate and author science identities through their engagement in a Saturday Science Enrichment community-based programme: Roots: "Ik ben Science!". This interdisciplinary programme draws on disciplines in science, technology, the arts, the environment and engineering and mathematics (STEAM) and using a curriculum anchored in culturally relevant/responsive and sustaining pedagogies. Afro-Caribbean students were selected to serve as participants in this study given the dearth of studies with this group of students in science education within the Dutch context.

Students from Caribbean backgrounds tend to choose among the disciplines in law, humanities and social sciences (CBS Annual Report, 2018). Very few earn a natural science degree, which is the track with the fewest students of Suriname and Antillean background. *Can students become what they cannot see*? This untapped potential is also apparent in the field of technology and science. However, tapping into the potential innovation and expertise that these young people can bring to the science disciplines, there first has to be a clear reform in the pedagogical approaches to teaching and learning in the foundational years of primary education. My research in employing a culturally relevant/responsive and sustainable pedagogy offers an opportunity to address the glaring inequalities and contribute to an area of the knowledge base that remain largely unexplored.

Brief Overview of the Relevant Literature

Quite a few researchers have argued the need for education to be culturally responsive: that is, responding to the students' cultures. I argue herein to adopt asset-based pedagogies (Paris, 2012) in out-of-school science teaching and learning experiences for students, especially those who identify with non-dominant groups and have been historically been marginalised in traditional schooling and other dominant-presenting spaces at large. In other words, education operates from a monocultural approach, which is problematic given that society is pluralistic with many diversities within cultures. Therefore, embracing the asset-based pedagogies of culturally relevant/responsive and sustainable in out-of-school science experiences disrupts the dominant discourse in science education. A discourse that traditionally positions minoritised students and their families in a deficit capacity.

The major tenets of CRP (Ladson-Billings, 1995, 2009; Paris, 2012) which will serve in the design of the intervention for the proposed study are the following:

- Academic success- learning
- Sociopolitical consciousness
- Cultural Competence

To highlight the partiality of science education to marginalised groups, I adopt an overarching framework of critical theory. Researchers adopting feminist theories and culturally relevant pedagogy have used the construct of science identity to examine student learning and participation in science, which is broadly defined as the perception of oneself as well as recognition by others as a science person (Carlone & Johnson 2007). Identity is under continuous construction and is reshaped as learning is enacted in formal and informal places of learning (Avraamidou, 2014). There are four components that Avraamidou (2014) summarised from the standpoint of a social theory of identity construction: practice, community, and identity that influence how we interact with each other, make meaning of the world we inhabit, take action and create biographies within a defined context (Lave & Wenger, 1998 as cited in Avraamidou, 2014, p. 3). In this study, I will use Figured Worlds as an analytical framework to extrapolate how students author and develop their science identities in various worlds or spaces. The idea that identity is continuously being reconstructed across time and space makes figured worlds apt as an analytical tool in this study (Carlone & Johnson, 2007).

From the premise that science is a figured world where members are recruited into, enact practices and become embodied in their roles in this figured world (Holland, Lachicotte, Skinner, & Cain, 1998). Figured worlds are sociocultural in construction and imagination that requires the interaction of people who assign meaning to the artefacts to direct practices (Holland et al., 1998). It is within the social, cultural, salient moments of interaction and individual enactment that form the basis for embodiment and identity construction. This study is an examination of how students are enacting their different selves, their multiple identities of *being* in the world, in different spaces.

The cultural world of science, manufactured and developed within a masculine white Eurocentric figured world, is a constant state of conflict as member participation requires constant mediation of our other figured worlds: that is, to what degree do students exert one aspect of themselves while silencing or limiting their other selves in the process of forming and authoring their science identity?

Luehmann (2016) argues that the “identities are constructed as we position ourselves and we are positioned” (p. 24). This positioning is reinforced in Figured Worlds in the social interactions that are crucial in identity construction. The social interactions are embedded in the context. This dialogic process of social interactions will be reinforced in the study where participants’ science identities are under constant construction and co-construction rooted in a community-based context. This unpacking and interpreting are reinforced in culturally relevant/responsive/sustainable pedagogies challenge the deficit-based beliefs of *what* science is and *who* can practice science.

Research questions

Situated within these theoretical perspectives, the proposed study will address the following research questions:

- How are Dutch-Caribbean students positioned within the culture of science? How do they form, negotiate, and author their science identities?
- How does the synergy of culturally relevant/responsive, and sustainable pedagogies support marginalised students’ authoring of strong positive (or not) science identities in community-based settings?
- In what ways does the programme *ROOTS: “Ik ben Science* influence marginalized students’ authoring of strong positive (or not) science identities?

Research Design, Methodology and Methods

The purpose of this research is to broadly examine how Afro-Dutch students position themselves and are positioned (or whether they are allowed to position themselves) in the Figured World of science as members of non-dominant cultural groups, in an out-of-school context. This section of the proposal will focus on the research methodology and data collection methods, including a description of the context and participants. The study follows a critical qualitative ethnographic case study approach. Ethnography has been adopted in the fields of social and educational research to understand and analyse the “perspectives and actions of how people see themselves and the world” (Hammersley, 2006, p. 4). To add another layer of dimension to the study, I will incorporate the case study approach in the critical ethnographic fieldwork.

Designed to bring to light the social and cultural experiences of daily living, case studies include observations, interviews and documentation of various sources to achieve this purpose (Hamel, Dufour & Fortin, 1993) and has crossed over into other disciplines such as education. For our purpose, the case is defined with a group of primary school-aged students of Dutch-Caribbean descent. Through a full immersion into the context of the study and the triangulation of data collected, ethnographic case study offers a rich and in-depth study of students in communities that have been historically marginalised.

I will be a participant-observer in this study as I float between moderate and active participation and observation as an insider and outsider of the study, engaging with facilitators, participants and co-participants. Participant observation (Yin, 2003; Spradley, 1980) is used in ethnographic research to gather data from the field as one participates in activities as well as observe interactions within the study context among participants.

Context

The context is defined by a 25-week community-based science programme, defined as a place where educators (education facilitators may not be licensed teachers), family members, the curriculum, and students interact and constantly inform each other. The culturally relevant/responsive and sustaining pedagogy will undergird the curriculum incorporating the everyday experiences students have with science. The science enrichment programme will hosted at on of the youth centres in the neighbourhood. Located in the eastern section of the city, it was once a farming community but has grown to 13000 residents in an urban city with a population of 202, 810 (www.cbs.nl). It is considered one of the most multicultural neighbourhoods, considered as a working class neighbourhood in a municipality that is considered one of the poorer cities (www.nrc.nl).

Participants

The participants will be recruited from the will be in the Beijum neighbourhood. The students for the programme will be recruited through school visits and dissemination of flyers to different neighbourhood groups. Specifically, for the study, three families will be selected through purposive sampling to achieve diversity in sampling in terms of family structure. For example, of those three, a single-parent family with a girl child would be chosen for an indepth study to examine the interaction of the child with members within the different contexts: the home with family, the science programme with peers and facilitators.

Methods

The programme will be a 25-week interdisciplinary enrichment programme incorporated in activities set around science, technology, engineering, arts and mathematics. The participants will meet every Saturday morning for 1.5 hours from February to June 2020. The project will be hosted at the neighbourhood youth centre. Data from educators, students and family members will be collected through ethnographic observations, interviews, personal diaries, and educator/student work over a period of 25 weeks. The analysis of the data will be done through the use of a combination of in-vivo and en-vivo coding strategies based on the theoretical framework and the themes that emerge through the data. Table 1 illustrates the kinds of data that will be used to respond to each of the three research questions.

Table 1: Parallels in research question, data collection and analysis

Research question	Participants	Data collection	Data analysis
RQ 1.	Students (8 to 13 years old.) Facilitators	Observation Interview Journal Student work	Content and thematic analysis with a combination of in-vivo and envivo techniques
RQ 2.	Students (8 to 13 years old.) Family members	Observation Interview Journal Student work	Content and thematic analysis with a combination of in-vivo and envivo techniques
RQ 3.	Students (8 to 13 years old.) Family members	Observation Interview Journal Student work	Content and thematic analysis with a combination of in-vivo and envivo techniques

Data collection will be collected for the duration of the project, which will be from February to June 2020, as illustrated in table 2. Data analysis will accompany the data collection. To establish credibility, I will employ triangulation, peer debriefing, and member checking.

Table 2. showing data sources in collection

Source	**Expected Encounters**	**Time allocation**	**Medium**	**Motivation**
Observations 1. Activities 2. Field Trips 3. Interactions	25 weeks 1.5 hours		Audio- and Video-taped	observe behaviours; transcribe conversations
Field notes	25 weeks	Recorded / context	Written	
Interviews				
Students Interviews	Three 45- minute interviews	Duration: beginning, middle, end	Audio- and video recorded	Semi-structured interviews elicit experiences and reflections with science in the past, present and wish for the future.
Family member	3 hour: 1 hour/ interview	Beginning, middle, end		Understand family involvement in the programme and science of everyday life at home.
Facilitator	3 hour: 1 hour/interview	Beginning, middle, end	Audio-and videorecorded	understand the instruction and relationship and interaction with students.

Photo elicitation		During interview		Help students: remember activities reflect on experiences. help family members recall experiences in science
Photos				Document activities
Student activities discussion/ journal reflections			Written	students’ responses to activities and interactions

Data Analysis

The preliminary data findings are not available for inclusion in this proposal; the project is slated to begin in February 2020. However, with the use of the constant comparative method by means of open coding strategies (Coffey & Atkinson 1996), the main concepts expected to be identified in the data will likely be associated with the main research questions.

The expected preliminary data analysis should reveal that a) the after-school programme plays a crucial role in supporting students’ development of their sense of agency as science persons; (b) explicit recognition by parents supports students in viewing themselves as successful science learners; (c) the programme supports students in positioning themselves as insiders into the world of science by allowing them to bring in their personal and cultural capital as evidenced through their enactment of their unique cultural practices and traditions.

Contribution

The study will propose an evidence-based theoretical framework for community-based programmes that aim to support minoritised students’ participation in science. A set of curriculum materials and activities that will be developed as part of the intervention can be used by informal science educators. Additionally, as an under-explored area, the findings will reveal the relationship between community-based science learning, student engagement, and student self-identification with science, through an analysis of their science identities.

Lastly, for the Dutch context, the findings will offer a unique contribution to the existing knowledge base given the scarcity of studies with Caribbean students, especially in the field of science education.

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Teachers’ indigenous worldview and its relevance to science teaching and learning

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Introduction

Individual worldviews differ as a result of differences in cultural beliefs, religion, race, gender and other markers of difference. This research explores teachers’ worldview of indigenous knowledge and its relevance to science teaching in the classroom. To achieve the accessibility of science in the classroom for learners in the South African context, the Department of Basic Education (2002) has included indigenous knowledge (IK) in teaching and learning sciences in the curriculum (C2005; NCS, 2011 and CAPS, 2011). This policy mandates teachers to integrate indigenous knowledge and science in their teaching pedagogical practices in the South African classroom. According to Ogunniyi (2013), Indigenous Knowledge System (IKS) is the local knowledge of indigenous people that is resident in a particular location. Currently, much focus has been placed on IK and its values due to its importance in relation to preserving cultural heritage, environmental sustainability and in challenging marginalization. It is also anticipated that integrating IK into the school curriculum may help to sustain IK in indigenous communities in Africa (Nakashima, Prott, & Bridgewater, 2000). The call by the Department of Education (DoE, 2002) for inclusion of IK in science teaching and learning was a bold attempt to preserve the African heritage and her ways of knowing, doing and acting of the South African indigenous people. Hence, the need to examine what views educators as stakeholders hold, relevant to IKS in a new, democratic South Africa.

Therefore, it is imperative that these researchers explore science teachers’ views of IK and how these views can be used in teaching and learning sciences in the classroom.

Background and Literature Review

The view of indigenous knowledge by scholars such as Ogunniyi (2007) and Odora-Hoppers (2004), among many, is that IK is in a knowledge dynamic, as it is evolves and develops (nonstatic) with time. IK is obviously influenced by its interactions with several other knowledge systems as well as with circumstances both externally and internally. From Dei’s (1993) perspectives, IK deals with the cultural traditions, worldviews, beliefs and values of the local people, which distinguish (separate worldviews) it from western science, because of its philosophical nature. Indigenous knowledge helps the rural people by informing their decisionmakings regarding certain vital issues within their localities. Their indigenous knowledge is important to all their cultural activities, which include the resources they use in practicing their culture, the social interactions that take place among the members of the community, their education, systems of classification and language, which is deeply rooted in a metaphysical framework (Dziva, Mpofu, Kusure, 2011). It was suggested that a philosophical framework be developed for a successful integration of IK into science teaching (Cronje, de Beer & Ankiewicz, 2015). According to these authors, the nature of indigenous knowledge framework encompasses ontology, epistemology, axiology, volition and methodological aspects, which are interwoven and inseparable. The ontological aspect deals with what the knowledge entails and what it means; the epistemological aspects involves the ways of knowing of indigenous people; the volition aspect deals with willingness, values, attitudes and beliefs of the indigenous people while the methodological aspect deals with "methods of wisdom in action" (p. 322). Western science (WS) and indigenous knowledge systems are seen by some researchers as similar and can therefore complement each other during teaching and learning in the science classroom while some emphasize on the differences of both knowledge systems, with the mindset that they conflict rather than complement each other (Vhurumuku & Mokeleche, 2009; Bohensky & Maru, 2011).

In South Africa, the studies on the implementation of teachers' indigenous knowledge by Ogunniyi (2004) and de Beer and Whitlock (2009) have been very significant in that they focused on practicing teachers in their classrooms. These studies provide insights into, particularly, those teachers that could influence the implementation of the integration of IK in the science curriculum. Integration of IK and WS in science teaching according to Hewson and Ogunniyi (2011) will provide learners with relevant foundation for effective science learning in addition to encouraging diverse viewpoints of the people in a diverse society.

Methodology

This study used a qualitative, case study, approach, and it focused on teachers' worldview of IK and its relevance to life sciences teaching in the classroom. A purposeful sampling is adopted for this research. The sample size investigated was twelve male and female life science teachers from four peri-urban high schools in Gauteng, South Africa. A questionnaire was administered to participating teachers to access their indigenous knowledge. The questionnaire was piloted in nonparticipating schools and was adjusted as needed. This research instrument focused on eliciting teachers' understanding and views of indigenous knowledge. The questionnaire was followed by interviews with each teacher who completed the questionnaire to understand teachers' views of the relevance of their local knowledge to science teaching and learning.

The questionnaire for this study was adapted and adopted from an existing instrument by Cronje, de Beer and Ankiewicz (2015). It was administered to explore teachers' views of Nature of Indigenous Knowledge (NoIKS) and Nature of Science (NoS). The questionnaire items were found suitable for this study because of its ability to elicit teachers' views of IK and the perception they hold regarding the knowledge. The questions were fine-tuned by the researcher and her supervisors after piloting before being administered to ensure feasibility and validity of the questionnaire. The interviews were done within the school context and were audio-recorded, and it served as raw data.

Data Analysis

The responses from the questionnaire were coded by assigning themes to the data. These themes were adopted and adapted from the knowledge synthesis model (Barnhardt & Kawagley, 2005). The themes were originated from the common intersection of NoS and NoIKS and were used to analyze the emergent data.

Some Preliminary Findings

This study is a work in progress. From the responses obtained from questionnaires and interviews, most participants view IK as "*holistic and it is made up of metaphysical and physical world link*"; it focuses more on "*application of practical skills and knowledge"*. Teachers revealed that, "*indigenous knowledge is science"*, and could differentiate it from WS. A good number of participants revealed that IK helps in *"teaching the new generation about whom they are and their history"* in the science classroom. From their responses, there was an indication that some teachers have ideas of how to incorporate indigenous knowledge into their life science lessons in their classroom. However, some are still not aware of their indigenous knowledge and how this knowledge could be a powerful tool for knowledge and identity construction, creative and critical thinking, and meaning making in the science classroom.

Implication and Recommendation

Teachers' unawareness of their IK has its implications in the science classroom and can constraint science accessibility to all learners of diverse cultures in the classroom, as teachers are likely not able to incorporate both worldviews. Also, teachers' inability to integrate IK and WS could be as a result of conflicting ideas teachers may have regarding both worldviews. "Creating a balance between two worldviews is the great challenge facing modern educators" who has the intention of incorporating IK and WS in their science classroom (Battiste, 2002, p. 202). Therefore, it is recommended, from this study, that teachers from indigenous background be exposed to new ideas regarding how they could integrate different worldviews to improve learning and meaning making in their classroom. Also, during the course of this research, some teachers recommended that a workshop on IKS and the possibilities of integrating it with westernized science should be organized for them regularly.

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Investigating science teachers’ practices on assessing students’ understandings of nature of science

Wonyong Park

Abstract

While numerous science curriculum reform documents around the world have emphasized the inclusion of nature of science (NOS) since the 1990s, there is a lack of empirical evidence on teachers’ responses to curriculum reforms focused on NOS and particularly how the engage in the assessment of NOS which is an unfamiliar form of knowledge to them. This study investigates South Korean science teachers’ experiences of classroom assessment in the wake of the recent curriculum reform that highlights NOS as an explicit learning expectation. The main interest of the study is to understand how NOS is assessed in Korean classrooms and what are the factors that mediate science teachers’ classroom assessment of NOS. Data sources include curriculum and policy documents, interviews of 30 science teachers, lesson observations and assessment materials. Implications will be drawn for policymakers and teacher educators to support the teaching and assessment of NOS-focused science curricula.

1. Focus of the study

NOS has become a major agenda for science education research and policy over the past three decades (Lederman, 2007). Teaching NOS in K-12 science education has been advocated for its diverse potential benefits in achieving scientific literacy, such as enhancing students’ understanding of scientific objects and processes, informed decision-making, responsible citizenship (Driver et al., 1997; Lederman, 2007). Along with the increasing awareness of the significance of NOS among researchers, recent curriculum reforms in many countries have introduced NOS as a major component of scientific literacy (AAAS, 1989; NGSS Lead States, 2013). While these and other science curriculum reform documents around the world have advocated and emphasised the inclusion of NOS in science teaching since the 1990s, there is a significant lack of empirical evidence on how teachers engage in the classroom assessment of students’ NOS learning.

One fact known from research is that teachers rarely make any attempts to assess students’ NOS understanding. In a study by Abd-El-Khalick, Bell and Lederman (1998a), none of the 14 teachers in their study made any attempt to formally assess NOS learning, although most of them believed in the importance of teaching NOS in schools. Another related, and problematic fact is that there have been surprisingly few empirical investigations on how

NOS should be assessed at the classroom level. Akerson et al.'s (2010) study is among the few exceptions that addressed the issue of classroom assessment of NOS. They found that experienced elementary teachers considered their students' developmental levels, special needs and academic abilities to assess NOS understandings (Akerson et al., 2010). Brock and Taber (2019) reported that English science teachers find NOS content particularly hard to assess fairly due to the ambiguity of assessment criteria, which became a major source of challenge in teaching NOS in schools. However, since these studies were conducted in the context of university-based professional development programme or a school curriculum where NOS is almost absent, there is minimal understanding of teachers' assessment practices of NOS in secondary science classrooms.

The primary purpose of this study is to better understand how teachers engage in the assessment of NOS in the context of the new national curriculum in Korea. By doing so, I aim to shed light on an underexplored territory within the scholarship on NOS and make contribution that can lead to improving the practice of NOS assessment in classrooms. The research questions are:

1. What are the curriculum policy contexts in which South Korean science teachers teach and assess NOS?
2. What are South Korean teachers' practices of the assessment of NOS?
3. What factors influence South Korean teachers' practice in the assessment of NOS?

2. Design and procedures

In the latest 2015 National Curriculum of Korea, a new subject named scientific inquiry and experimentation (SIE) has been introduced in an attempt to facilitate the students' understanding of NOS through inquiring how scientific knowledge is produced and applied (MOE, 2015). The new curriculum takes an explicit approach to teaching NOS by stating specific learning outcomes related to NOS and teachers are expected to teach and assess these aspects of NOS. To investigate teachers' practice of NOS assessment in the wake of the new national curriculum, 30 science teachers will be invited for interview, and up to 10 of them will be invited for lesson observations.

Table 1 shows an outline of the study. For research question 1, I will draw on key documents related to the curriculum to provide an outline of how the curriculum policy documents understand the teaching and assessment of NOS in South Korea and what they expect for the teachers with regard to these tasks. For research question 2, I will use interviews, lesson observations, assessment plans and materials to investigate the commonalities and differences among participants with regard to these aspects. The aim is to provide a detailed descriptive investigation of various aspects of teachers' practices such as their interpretation of the curriculum goals related to the assessment of NOS, perceived aims of the assessment of NOS, the strategies used for assessing different NOS aspects, and the challenges that teachers encounter while assessing NOS. For research question 3, an in-depth examination of multiple cases will be used to identify the potential factors that influences teachers' assessment practices and how these factors relate to one another. In so doing, particular attention will be given on the nature of the curriculum knowledge being taught and assessed (i.e., NOS), which is more subjective, social and controversial than the traditional content knowledge of science, and how such differences are (or are not) translated into teachers' assessment practices.

Research question	RQ 1. What are the curriculum policy contexts in which South Korean science teachers teach and assess NOS?	RQ 2. What are South Korean teachers' practices of the assessment of NOS? RQ 3. What factors influence South Korean teachers' practice in the assessment of NOS?
Participant	N/A	30 science teachers
Method	Document analysis	Interview, lesson observation (selected interviewees)
Data Source	Curriculum and policy documents, newspaper articles, course syllabi and assessment plans of each school (available online via School Information Database)	Interview transcripts, lesson observation transcripts and field notes, lesson materials, assessment materials
Potential method of analysis	Content analysis	Thematic analysis combined with a case study of selected participants

Table 1. Overview of the study

In the following, I describe my pilot project with two teachers that led to the conception of the main project and the preliminary findings relevant to the proposed research questions. After introducing the context, design and emergent themes from the data, I explain how this pilot study guided the main study due to be undertaken in Spring 2020. Since the pilot study was a “process” rather than an “outcome” of the project, the preliminary findings reported below do not directly answer the three research questions, but they still provide initial clues about teachers’ understandings and impressions about the new curriculum that could influence their practice of assessment.

3. Preliminary findings from the pilot study

The pilot fieldwork was carried out over a period of five weeks and mainly involved individual interviews with teachers and lesson observations. Participants were two teachers, Young and Jean, who taught the new curriculum in an urban school in Korea. The teachers were invited for one or two interviews, in which they were asked about their perceptions of NOS, the new curriculum and the teaching of these in their lessons. The interview questions consisted of both broader questions on their knowledge and practice on the teaching of NOS and specific questions inspired by the lesson observations. Each interview spanned between 40 and 60 minutes. Along with the interviews, two 50-minute lessons were observed for each teacher.

The pilot data was qualitatively analysed following the principles of thematic analysis (Braun & Clarke, 2006). First, the transcribed data were read multiple times to familiarise myself with the data and identify interesting themes regarding teachers’ understandings, practices and concerns about the teaching and assessment of NOS. Given the exploratory nature of the pilot study, codes were generated inductively from the data, rather than from a preexisting theoretical account. These initial codes were further developed and organised through several iterations of revisions to generate emergent themes.

Teachers have their own way of understanding the NOS-centred curriculum

The teachers developed different understandings of and approaches to the NOS-centred curriculum. Young had no doubts about the importance of SIE and NOS per se. However, she still mentioned that the teaching of the new curriculum would “greatly depend on what individual teachers already know and have” (i.e., their knowledge and beliefs), saying that because she knows more about earth science, she would likely teach more NOS aspects related to earth science. In contrast, Jean was not completely convinced of the idea of teaching NOS as a separate school subject, although she thought it is a “fresh” curricular attempt.

In addition, each teacher had their own view on what should be emphasised when teaching the new curriculum. Young emphasised making connections between NOS and examples. GFollowing students' group presentation on the paradigm shift, she kept asking *"Why is this an example of the paradigm shift?"* to the presenters and other students to prompt students' making connections between examples, and between NOS aspects and examples. In addition, she also encouraged students to think about other NOS aspects found in the example. On the other hand, Jean's main emphasis was to let the students experience and feel "how difficult and sophisticated" scientific discovery is. She also stressed several affective aspects such as the collaboration among group members and listening to other students' presentations.

Teaching NOS is not the same as teaching science

Both teachers acknowledged that teaching the NOS-centred curriculum is, in many ways, different from teaching science. Such differences became clear when they compared the new curriculum with the previous science curricula. For example, Jean mentioned that the most distinct feature of the new curriculum is its "real" and "authentic" examples:

> *"SIE deals with what science is and how we should approach it. This seems new because it makes students follow and repeat what scientists really did. The past curricula only said what inductive method is, but this curriculum has a real example for student activity so would have been more authentic to them." (Jean, interview)*

More specifically, when Jean was asked about the differences between teaching about the periodic table in a chemistry lesson and in an SIE lesson, she answered that student-led activities is the most distinct aspect of the latter:

> *"The activity is different. The historical account used to take only a few minutes [in the chemistry curriculum], but it's supposed to be an hour in SIE. At first I didn't want to let students do the ['Make your own periodic table'] activity since it was hard to expect any meaningful results. But I wanted students to feel that what Mendeleev did is not an easy job and is difficult so did it." (Jean, interview)*

On the other hand, Young emphasised that science cannot be separated from its human aspects (that is, NOS), and that students should be taught about this:

> *"After I studied the nature of science in the grad school, I always say to my students, that never think there is an answer in science. It's the same as human lives. Diversity … Just as you can't do anything about something even when you think it is wrong, there are some theories and explanations like that." (Young, interview)*

While stressing the similarities between science and NOS, she also noted that teaching NOS is not like teaching earth science but needs a lot more discussions and reflections, given the controversial and interpretive characteristics of the knowledge. She also thought that teachers would need to develop extra skills to deal with the NOS-centred curriculum, which is consistent with what research has suggested about NOS teaching (Akerson, Abd-El-Khalick, & Lederman, 2000; Allchin et al., 2014).

Assessment and grading are major concerns in their teaching of NOS

Because it was the first term of teaching SIE for both teachers, a large portion of their pedagogical concerns were related to the student activities and grading. This was in part due to the school culture and socioeconomic status of students as described above, which made both the teachers and students particularly concerned about the "fairness" and "differentiation". Given the culture of competition, accountability and the enormous pressure on the college entrance in the country, the teachers thought that the success of the new curriculum would largely depend on assessment and evaluation:

> *"I hate to say this, but the future of SIE would depend on how it is assessed and included in the college entrance system, because it decides everything in this country." (Young, interview)*

Both teachers mentioned that the change in the grading policy from 9-level grading system to 3-level one impacted how they teach and assess the new curriculum. Under the new, less stratified grading system, both teachers and students felt less pressure, and teachers were inclined to assessments based on student presentations and homework rather than written exams. Young mentioned that she liked this change because she could have more discussions with students:

> *"I can do longer 'questions and comments' after the presentations because there are no written exams for SIE in our school. If I were responsible for teaching everything in the curriculum, that wouldn't have been possible." (Young, interview)*

The preliminary findings reported above provided useful information about teachers' practice of teaching the new Korean curriculum with an explicit focus on NOS. As a result, teachers' practice of assessment of NOS has been selected to be the main focus of the project, on the basis of its perceived importance by teachers and the lack of research on the topic. The pilot study also allowed identifying several potentially important themes regarding NOS teaching such as the difference between assessing science and NOS, the influence of the college entrance system on the classroom assessment, and the interaction between teachers' knowledge and practice regarding the assessment of NOS.

4. Contributions of the study

In general, the study will contribute primarily to the current literature on the assessment of NOS understandings. Given that assessment has a great impact on teachers' curriculum interpretation and implementation, investigating the challenges and opportunities that teachers experience when assessing NOS in the wake of the new curriculum will help science educators navigate the directions for NOS-oriented science curricula. In addition, although the current study focused on NOS, the findings also provide important clues for classroom assessment of other aspects of the science curriculum such as scientific practice and argumentation.

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Concept learning in science and technology: helping students to structure better their knowledge system when learning the concept of force

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Introduction

This PhD is about the design, implementation and evaluation of an instructional intervention based on the *four-component instructional design* (4C/ID) model. The aim is to help students to elaborate a well-structured knowledge system in their memory when learning some difficult concepts in science. As the literature shows, student conceptual understandings are a major issue in science for decades, and the learning of special concepts is not self-evident. For instance, students have recurrent and obvious learning difficulties when learning the force concept in Newtonian mechanics. It has also been proved that classical instructions have little impact on them. The research is experimenting an educational device aiming to help teachers to teach the force concept better both in science and technology education. ▪

Educational context

In 2016, France's results on the PISA survey were mixed. Only 8% of high-performing students could use abstract scientific concepts to explain complex and unfamiliar phenomena (OECD, 2016). Regarding these observations, debates on student learning issues are, more than ever, reaffirmed. Several educational reforms have been initiated, but with no satisfactory results. Therefore, for instance, curricula should focus more on how to elaborate well-designed teaching and learning methods. In this line, a focus on knowledge acquisition that make sense socially and culturally is then needed (Ginestié, 2017). Such reconsiderations require new perspectives for learning, and a re-examination of thinking modes to be revisited to better situate knowledge. Consequently, educational systems that consider the construction of deeper knowledge in student memory are a major challenge for more effective teaching and learning processes.

The addressed issue

This research addresses the issue that learning some difficult concepts, such as force, implies to construct a *complex knowledge system* in the learner's cognitive system. This construction requires systemic learning approaches that consider, inevitably, the student's cognitive architecture. Such approaches need to emphasize the integration of knowledge, skills and attitude in a high level of coordination. In the next paragraph, I propose briefly some elements permitting to capture such an approach.

Review of literature: Knowledge approaches in conceptual change

The literature has referenced many epistemologies focusing on student conceptual understandings. In this research, I focus first on two models in conceptual change: Knowledge-as-Theory (KaT) and Knowledge-in-Pieces (KiP) approaches. One of the contrasts between these lies in the way they consider the evolution of naïve ideas. KaT considers naïve ideas as coherent, implicit (Vosniadou, 2013), while KiP postulates that ideas are intuitive and made of many fragmented and inarticulate primitives that are context-dependant (diSessa, 2017). KiP epistemology, which seems more relevant to me, assumes that learning is a transformation of one complex knowledge system into another (diSessa, 2018). But, students lack in articulating knowledge elements in memory (Bastien, 1997; Schneider & Stern, 2010).

Some important challenges found in students' learning can be situated to some learning strategies that deal with complexity without losing sight of separation and interactions between knowledge elements. An important aspect of students' failure can be found in how they manage information and structure their knowledge within a subject. It necessitates a well-organized learning progression. Another issue is cognitive loads which can be generated because of a high knowledge element interactivity when learning a concept. These issues are discussed in the model described below.

The four-components instructional design (4C/ID) model

To design instructional approaches in complex learning domain, many models have been developed. Among them, the 4C/ID-model focuses on authentic and complete learning tasks (whole-tasks) as the main guideline for learning and teaching. Unlike KaT and KiP, the 4C/ID-model presents different but converging ideas about how intervention should be designed. A basic assumption is that students' failure in knowledge construction and transfer can originate from the traditional approach of most instructions that used to reduce the complexity of contents in a level they can be taught easily or "*piece by piece*". However, the 4C/ID-model aims to deal with complexity which is characterised by high element interactivity by using a *simple-to-complex* learning progression.

The 4C/ID model (van Merriënboer & Kirschner, 2018) is designed based on the Sweller's cognitive load theory (Sweller, Ayres, & Kalyuga, 2011) and the Mayer's theory of multimedia learning (Mayer, 2014). Cognitive load theory (Sweller, van Merriënboer, & Paas,

2019) explains how the information processing induced by the learning tasks can affect student ability to process new information and to construct knowledge in long-term memory. To design such instructions, the 4C/ID-model introduces four interrelating blueprint components in complex learning: *learning tasks, supportive information (the theory), procedural information (the how to's)* and *part-task practice*. This model inspired the design of an educational instruction to teach the Newtonian concept of force which is dealt with in my PhD thesis.

Students' misconceptions about force

The choice of the force concept follows a long development in the history where many debates broke out between scientists since Antiquity (Coelho, 2010; Lehoucq & Lévy, 2003) and more recently between technologists (Jouin, 2002). According to Jouin (2002), force is also the fundamental concept of mechanics in technology. In science, the concept received different characterizations usually labelled as misconceptions: Aristotelian, Galilean, Newtonian, etc. similar to those in technology. From the literature, I retained primarily four interpretations of students' misconceptions about force (Ioannides & Vosniadou, 2002): (1) *Force is an internal property of physical objects*, (2) *Force is an acquired property of physical objects that explains their movement*, (3) *Force is the interaction between an agent (animate) and an object (inanimate)*, and (4) *Force is the interaction at a distance between a physical object and the earth*. These meanings supported an exploratory study that probes French teacher views of student misconceptions. However, given that these meanings are less coherent to KiP (diSessa, Gillespie, & Esterly, 2004), this research considers a more global definition of Newtonian force concept. It is based on six conceptual dimensions (Hestenes, Wells, & Swackhamer, 1992): *kinematics*, the *three Newton's laws of motion*, *the superposition principle* and *the types of forces*.

Research question

In France, the force concept is taught within the physics and technology curricula in high school (grades 10-12). Since these subjects do not approach the concept identically and since most of students perceive these two disciplines as distinct and separated things as they are taught separately, students developed a compartmentalized thinking about force that do not foster their understanding and do not help them to better structure their knowledge system. They then struggle to get a complete view and sense of how the concept is organized. So, regarding the theoretical elements, this research aims to answer to the following questions:

- Can an instruction developed within the 4C/ID-model be effective in terms of student learning about the force concept?
- How can this instruction help students to better restructure their knowledge system when learning a scientific and technological concept such as force?
- Can an intervention associating physics and technology improve student learning about the Newtonian concept of force within a *simple-to-complex* learning progression?

I hypothesized that it is necessary to help learners to gather the knowledge elements of the complex system, and to build relations between these. To test this hypothesis, I defined an educational device in both physics and technology. This intervention will attend to define how teachers should offer support to students to help them elaborate a well-structured knowledge system and to foster their understanding process (Musial, Pradere, & Tricot, 2012).

Design and methods

To investigate student learning, we adopt a triangulation of methods. First (1), an exploratory survey based on a research questionnaire has been addressed to French teachers in science and technology from South of France to investigate their views about student misconceptions and learning difficulties, possible relationships between these, and the extent to which these are dependent on declared teaching methods (Author, *under review*). (2) This survey has been followed by an individual protocol analysis with pre- and post-tests before and after teaching interventions (using the Force Concept Inventory FCI and the Mechanics Baseline Test MBT). Students in grade 11 (*N* = 10, *Mean age* = 16.75) have been experimenting the research. The activities are described in Tables 1 and 2. (3) Finally, a micro genetic learning analysis through clinical semi-directive interviews (diSessa, 2017; Parnafes & diSessa, 2013) was conducted with both teachers and students to investigate student knowledge system.

In physics, the first task class aimed to construct the knowledge elements of the two kinds of forces (contact: friction, and distant: gravitational). The second task class was intended to help students build relationships between force and energy through the use of the energy conservation principle. In technology, the different forces were strengthened and an elastic force was introduced in the first task class. In the second task class, internal forces and stresses were discussed to explain the effects of forces on the structural model of a system. Finally, rotational force or torque (defined by *force* * *lever arm*) was taught. The interventions were approached using a *whole-task* learning progression as prescribed within the 4C/ID model. Interactive simulations were used in physics courses, and both interactive simulations, simulation analysis and CAD design in technology.

Table 1. Component 1 of the 4C/ID: Designing Learning Activities in Physics

	Task class 1	**Task class 2**
	A11. Contact and Distant Forces	***A21. Forces and Energy***
Purpose	Exploring contact and distant forces	Examining connection between force and energy through the conservation of energy
Artefact	Projectile motion (PhET)	Skate park (PhET)
Context	Preparing to launch a rocket	Energy conservation
Duration	2 sessions per week: 1 activity (2h) and 1 interactive lecture demonstration (1h).	

Table 2. Component 1 of the 4C/ID: Designing Learning Activities in Technology

	Task class 1	**Task class 2**
	A11. Contact and Elastic Forces	***A21. Internal Forces, Stresses***
Purpose	Understanding the effects of forces on a mechanism's functioning.	Analysing the effects of internal forces on the structural model of a system or an object.
Artefact	3D Rocker Arm mechanism	3D Crank Rod
Context	Internal combustion engine of automotive. Simulation Analysis.	CAD Structural Analysis
Duration	1 activity (2h)	1 activity (2h)
	A12. Gravity Force	***A22. Torque by Contact Forces***
Purpose	Exploring the effects of gravity in the design of spaceships	Understanding rotational force
Artefact	Gravity and Orbits (PhET)	Beetle on a rotating plate (PhET)
Context	Launching a rocket	Rotating shaft functioning
Duration	1 activity (1h)	1 activity (2h) and 1 lecture (1h)

Data analysis

The triangulation aimed to better understand the complex process of teaching and learning. The collected data were essentially written and electronic documents, vocal and screenshots recordings. Both quantitative and qualitative analyses were used to analyse these data, and will help to track the profile of each student. Quantitative data concerned scores from the inventories (FCI and MBT) were analysed by computing an exploratory factor analysis (EFA) which would help to highlight correlations between items. (1) Written productions were examined using theory activity which aims to understand defined tasks and student activities before and during the interventions (e.g. Ginestié, 2008). (2) Visual data (screenshots and visual representations) were assessed using qualitative methodologies (e.g. Banks, 2007). (3) Learning interactions including argumentations, vocal recordings and interviews have been transcribed and were interpreted based on the literature (e.g. Aufschnaiter, Erduran, Osborne, & Simon, 2007; Erduran & Jiménez-Aleixandre, 2008; Leander & Brown, 1999; Parnafes & diSessa, 2013).

Results

Results from the individual protocol analysis are currently under analysis. However, first results for students in grade 11 showed that the intervention had moderate positive effects on learning progression since learners got a more comprehensive view about force throughout the whole intervention (in both physics and technology). Table 3 below summarized students' scores from the Force Concept Inventory (FCI) used as pre- and post-tests.

Table 3. FCI scores before and after the interventions in physics and technology. *N* = 11, *Mean age* = 16.75. Grade 11.

	Pre%	**Post%**	**Cohen's d effect size**
Physics	25	28	.21*
Technology	28	31	.30**
Whole intervention	25	31	.50**

**low, **moderate or medium effect size*

Results (Table 3) showed that students' average scores increased slightly, both for physics (from 25% on the pre-test to 28% on the post-test) and for technology teaching (from 28% on the pre-test to 31% on the post-test).

To learn about how substantially students' knowledge system of the subject changed as a result of the intervention, we calculated Cohen's *d* effect size (Cohen, 1969). As shown in Table 3, the effect was low (*d* ~.2) after the physics course but it was medium (*d* ~ .3) after the technology teaching. Globally, the research intervention showed a moderate effect size (*d* = .5) of the change between the first pre-test and the last post-test for this research intervention. When comparing teaching effectiveness between disciplines, technology teaching was moderately more effective (technology had 2 additional activities) than physics, but the combination of the two interventions showed better results regarding the effect size (~ .5). However, to be more efficient, the progression for complex learning needed to last over a longer duration as suggested by van Merriënboer and Kirschner (2018).

Discussions

The implications of the whole-task approach through an active engagement of students, effective teaching strategies and guidance, the interactive simulation and structural analysis, pair and group discussions, as well as group interactions appeared to be beneficial to student learning. Students became more reflexive to the occurrence and the nature of forces. Their argumentations showed stabilities when it comes to define the kinds of forces and torque involved in the analysis of mechanical interactions in physics and technology. Interactive simulations were constructive since it improved student motivation and engagement to study a complex concept such as force, and regulated teaching guidance (Adams, Paulson, & Wieman, 2008; Chamberlain, Lancaster, Parson, & Perkins, 2014). These simulations presented first in physics aimed to restructure students' mental models of the concept in a way they can concretely understand what types of forces are in use in classical physics. This step was important since students should have some knowledge about the subject before getting the necessary resources to solve problems (diSessa & Wagner, 2005; van Merriënboer & Kirschner, 2018). Besides, familiarity with the content of a task is a main indicator of whether a high-quality argumentation can be attained (von Aufschnaiter, Erduran, Osborne, & Simon, 2008). Thus, activities were designed to ease teaching guidance and to foster students' self-regulation of their learning. And teacher did not provide heavy guidance as it could affect students' interactions (Chamberlain et al., 2014).

Within the physics and technology teachings, elaborating both (1) the different *kinds of forces* and (2) *forces and energy* enhanced a better elucidation of student misconceptions, in particular regarding the *impetus* force of motion (McCloskey, 1983; Viennot, 1979). Researchers (e.g. diSessa, 2018) described scientific knowledge as networks or systems related to sub concepts and principles. This psychological process of elaboration (Weinstein, Madan, & Sumeracki, 2018) (making meaningful associations with a specific concept) helped learners to better integrate their intuitive ideas in cohesive conceptual structures (diSessa, 1993).

The designed intervention associating physics and technology teachings improved student learning about the Newtonian concept of force within a whole-task perspective, with a moderate effect size (~ .5). Students could readapt, restructure their existing mental models about the concept (Parnafes, 2010). However, an exploratory factor analysis (EFA) would help to have a better understanding of correlations between items of the FCI that were better involved in students' scores. Should it be the case, a large sample size (*N* > 200) needs to be considered. Also, students' argumentations and visual data are still under analysis and will provide important insights of the dynamics of their knowledge system as a result of the implementation of the teaching-learning process based on the whole-task approach.

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11. Please Stay Touch

Below you can find a **web profile link** for each of your fellow VDN participants so you can stay in touch.

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