Eilish McLoughlin
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Bridging Research and Practice in Science Education

Selected Papers from the ESERA 2017 Conference

Springer

Contributions from Science Education Research

Volume 6

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Introduction

This edited volume is composed of selected papers that were presented at the 12th European Science Education Research Association (ESERA) Conference, held in Dublin, Ireland from 21 to 25 August 2017. The ESERA community consists of professionals with diverse disciplinary backgrounds, ranging from natural sciences to social sciences. Such diversity provides a broad range of research, practice and policy of science teaching and learning as reflected in this volume.

ESERA is an international organization for science education researchers and science educators, and it aims to (i) enhance the range and quality of research and research training in science education; (ii) provide a forum for collaboration in science education research; (iii) represent the professional interests of science education researchers in Europe; (iv) seek to relate research to the policy and practice of science education in Europe; and (v) foster links between science education researchers in Europe and elsewhere in the world (www.esera.org). The biennial ESERA conference is the main forum for direct scientific discourse within the community, for exchange of insightful practices, and for extending networks among the researchers and educators.

The contributions in this volume showcase current orientations of research in science education. Overall, this book will be of interest to an international audience of science teachers, teacher educators and science education researchers who have a commitment to evidence-based and innovative science teaching and learning.

Reflecting on the ESERA 2017 Conference

The ESERA 2017 Conference theme was Research, Practice and Collaboration in Science Education, and underlying aspects that are of great relevance in contemporary science education research. The conference theme called on researchers to reflect on different approaches to enhancing our knowledge of learning processes and the role of context, designed or circumstantial in learning and instruction - across formal, informal and non-formal contexts.

The organization of the ESERA 2017 conference was jointly undertaken by Dublin City University and the University of Limerick through their STEM education research centers of CASTeL and EPI-STEM. In total, 1519 single and multipaper proposals were submitted to the conference in early 2017. Of the 986 proposals submitted for single oral presentations, 663 were presented as such at the conference. A total of 260 proposals were presented as interactive posters and this included contributions from 62 young researchers who had attended the ESERA summer schools - 39 of the participants of the ESERA 2016 Summer School and 23 of the participants of the ESERA 2017 Summer School. In total, 59 symposia (each with four papers) were presented at the conference, of which 16 were invited symposia. Each symposium was organized by a coordinator around a specific topic and each of the papers addressed the topic from different perspectives by authors from different countries. Twelve sessions were presented in the format of an ICT demonstration, hands-on workshop or as a World Café.

The conference week was thus highly scheduled with single oral presentations, symposia, interactive posters, ICT demonstrations and workshops divided into 18 different strands based on their topic (see www.esera2017.org). In addition, the conference also invited four plenary talks by prominent researchers, focusing on (i) Equity in Science Education: Science as a Tool Rather than a Destination; (ii) Science Education: A Balancing Act Between Research in University, Daily Instruction in Schools and Politics in Education Ministries; (iii) The Good Science Teaching Quest(ion): Constructions and Contestations; and (iv) Broadening our understanding of transformative science learning contexts: the role of design, collaboration, and digital technologies. After the conference, all presenters were invited to submit revised and extended papers on their conference presentation to the electronic proceedings of the ESERA 2017 Conference, which is available at https://www.esera.org/publications/esera-conference-proceedings (Finlayson, O.E., McLoughlin, E., Erduran, S., & Childs, P.E. (Eds.) (2018). Electronic proceedings of the ESERA 2017 Conference: Research, Practice and Collaboration in Science Education. Dublin, Ireland: Dublin City University ISBN 978-1-873769-84-3).

The ESERA 2017 Conference was attended by 1522 science education researchers from 53 countries around the world and thus the conference was indeed a very international meeting. About two thirds of the participants came from 29 European countries, with the remainder of the participants coming from 24 different countries across North America, South America, Asia, Australia, Africa, and Middle East. While presenting one's own research and engaging with others in discussion was one of the most important aspects of the conference, having an opportunity to meet other science education researchers was just as valuable. The discussions at conference sessions provided opportunities for researchers and practitioners to exchange their experiences and approaches. The countless encounters with other researchers throughout the week enabled the participants to strengthen their existing networks, make new acquaintances and set seeds for future cooperation. For the first time in an ESERA conference, one of the workshop sessions was conducted in the form of a World Café discussion on how to combine content knowledge and pedagogical content knowledge learning during university teacher education. At thematic

discussion tables, the participants at this World Café were invited to present their ideas (e.g., using printed materials or short oral/poster presentations) and to co-develop ideas for how to improve the integration of different aspects of teachers´ professional knowledge and competencies across the participating countries.

In addition to the formal conference program, the participants had an opportunity to attend pre-conference workshops and different receptions, and take part in other excursions around Dublin City and other Irish tourist destinations. The general atmosphere at the conference was one of collaboration and collegiality. The participants were delighted to be at ESERA in Ireland for the first time and received a "Céad Míle Fáilte"—a hundred thousand welcomes—from the local organizers. A local group of 54 individuals formed the support team for presenters throughout the conference week. This team consisted of academic faculty members, postdoctoral researchers, postgraduate and undergraduate students in science education from the two host universities of Dublin City University and the University of Limerick. ESERA 2017 participants got the opportunity to flavor the famous Irish "ceol agus craic" (music and fun) at the Traditional Irish Céilí night on the evening before the final conference day and it was wonderful to see hundreds of participants joining in Traditional Irish Dancing—an experience they will hopefully cherish for many years to come.

Highlights of the Chapters

This volume presents research identified at the ESERA 2017 conference as particularly interesting in the field of science education. The topics discussed will generate interest and spark debate within the community of science education researchers and science educators. We, the editors, are very grateful for all the work carried out by the international panel of strand chairs and reviewers who made it possible to include these selected papers in this compilation. Following the conference, the strand chairs recommended interesting conference contributions as possible papers for this book. We invited 44 recommended authors to submit full manuscripts. Based on at least two reviewer reports, we determined the 22 papers selected for this book. Thus, the papers underwent a rigorous scientific review process, guided by the editors, before being accepted into this volume in their final form.

This volume contains 22 papers as chapters that each take a specific perspective of an aspect of contemporary science education. The chapters are multifaceted and examine different science education phenomena. To help the reader, the chapters are discussed under four themes: Innovative Approaches to School Science, Emerging Identities in Science Education, Learning Progressions and Competences, and Enhancing Science Teacher Education.

In what follows, we will highlight the main aspects in each particular theme. This will provide the reader with an overview of the variety of different subjects, contexts, and research approaches.

Innovative Approaches to School Science

The volume begins with a collection of six contributions that discuss approaches for bridging research and practice to enhance science education in our schools and report on a range of innovative approaches carried out with students aged from 5 to 16 years old. In this context of enhancing science teaching and learning in our schools, **Peter Labudde**, one of the keynote speakers at ESERA 2017, highlights eight foci that are pertinent for science educators to consider. Each of these foci is presented and illustrated by paradigmatic examples from recent research projects in science education. Foci 1 to 4 consider how research in science education can be translated into everyday practice and policy, e.g., developing concepts for instruction and responding to the needs of schools. Foci 5 to 8 are concerned with how everyday practice and policy can influence research in science education, e.g., reframing recent scientific research as science content for schools, considering non-formal teaching-learning processes.

In their chapter, **Manuel Bächtold** and **Valérie Munier** present an example of a strategy for teaching the concept of energy at high school based on history and philosophy of science and building on the historical research of Joule and Rankine. This teaching-learning sequence was created through a researcher–teacher collaboration. Evidence of the effect of this history and philosophy of science approach on student understanding in this context is presented. This chapter highlights this approach could be an effective teaching strategy for other topics in science.

The next two chapters propose that embedding multiple external representations (MERs) in science education is key to developing students' understanding of science and scientific literacy. **Marie-Annette Geyer** and **Gesche Pospiech** discuss an explorative, qualitative laboratory study in which 17 pairs of students (aged about 14 years) worked on physical-mathematical tasks requiring different transformations of representations of functional dependencies. Qualitative content analysis was used to examine students' written work and discussions to elucidate possible strategies and thinking patterns of the students while they were transforming representations. **Christina Beck** and **Claudia Nerdel** remind us that science can be understood as a multimodal discourse, and dealing with multiple external representations becomes a premise for learning and developing representational competence. Their study analyzes the use of different representations (diagram, schema) and the relationship between representational competences (information selection and interpretation, construction, translation, and transformation) in three different biological contexts (ecology, physiology, genetics).

The authors **Andreas Larsson**, **Matilda Stafstedt,** and **Konrad J. Schönborn** remind us that our everyday language is filled with all sorts of metaphoric relations (e.g., analogies, metaphors, and metonyms). Metaphoric relations—the idioms in which we talk about one phenomenon in terms of another—are linguistic units that are an important constituent in the way we reason about and understand the world around us. Their study investigated eight groups (3–4 pupils per group) of

fourth-grade pupils' use of metaphoric relations while using thermal cameras to explore "heat" at a science center. The pupils' use of the thermal cameras provided them access to thermodynamic phenomena through unique sensory and nonsensory experiences in an informal learning context. The authors raised the need for future research to explore how these metaphoric relations can be exploited as sense-making activities in the classroom.

Estelle Blanquet and **Eric Picholle** discuss a study involving 62 five-year-old children. These young learners were presented with a bottle in which a hole had been pierced and asked if it was possible to stop the water from flowing through the hole without closing it. The pupils were then shown that this result can be obtained by screwing the bottle's cap. The focus of this study was to investigate the ability of children to consider a counterintuitive experiment as "science," and able to consider its reproducibility—or do they consider this experiment as magic? Are the children able to justify their position? How do they consider the necessity of testing the reproducibility of an experiment? The authors raised the need for further observations to establish whether an explicit focus on the reproducibility of an experiment performed in the frame of scientific inquiry would allow pupils to get a better grasp of scientific concepts and the notion of reproducibility.

Emerging Identities in Science Education

This section of the book includes six chapters that deal with a range of issues and themes related to students' learning of science. The themes covered include not only foundational issues such as motivation and self-efficacy but also particular skills such as computing skills and the ability to engage in scientific inquiry. The authors use a range of methods including qualitative and quantitative methods to highlight how science teaching and learning can be improved. An emerging theme is the newly conceptualized account of activism in science to encourage students to take an active role in social matters that have scientific undertones such as climate change. In her chapter, **Jenny M. Hellgren** highlights the importance of students' motivation in science lessons, and proposes a new model for considering motivation in science education. The author conceptualizes motivation as a multi-level and dynamic construct, and captures contextual and situational motivation of relevance for the science classroom. The proposed model combines multiple theoretical perspectives to produce a model of motivation that supports a multi-perspective view of motivation of relevance to complex classroom situations. The proposed model supports multiple methodological perspectives to study motivation in science classroom situations.

The authors **Anssi Salonen, Anu Hartikainen-Ahia, Tuula Keinonen, Inês Direito, John Connolly, Annette Scheersoi,** and **Lara Weiser** examine lower secondary school students' knowledge of specific working life skills. The authors report on a multinational research project involving a large sample of participants from the UK, Finland, and Germany. Using open-ended questions and content

analysis, they examine students' perceptions of working life skills needed in science-related careers. The results reveal that the students have a great deal of knowledge about working life skills - often stereotypical. The authors suggest that students need learning experiences including presentation of working life skills such as interacting with professionals and their real work-life problems, open-ended inquiries, and balanced team working to increase their awareness and perceived relevance of careers.

Anne-Kathrin Peters draws attention to students' computing skills and reports a longitudinal study conducted with the aim of exploring computing students' changing relationship to their field of study during their university education. Students from two study programs were selected to follow through interviews at the end of the first three study years. An early insight was that students' reflections on their interests in computing can change drastically, for example, from being someone interested in combining art and computing to being interested in back-end problem solving. Hence, the author uses social identity theories to reason about changes in student reflections.

Albert Zeyer, Nuria Álvaro, Julia Arnold, J. Christian Benninghaus, Helen Hasslöf, Kerstin Kremer, Mats Lundström, Olga Mayoral, Jesper Sjöström, Sandra Sprenger, Valentín Gavidia, and **Alla Keselman** capitalize on the expertise and experiences of an international group of science educators to investigate complexity as a key feature for understanding the role of science knowledge in environmental and health contexts. The authors point to the fact that complex systems are, in principle, not predictable. In different contexts, different mechanisms produce various, sometimes completely unexpected results. The role of complexity in fields such as science, health, and environment implies the need to develop future citizens who understand the delicate relation between predictability and uncertainty and to empower them for wise decisions about societal and personal well-being. The authors present a series of studies which illustrate the importance and challenges of introducing the issue of complexity into science education.

The chapter from **Larry Bencze, Lyn Carter, Audrey Groleau, Mirjan Krstovic, Ralph Levinson, Jenny Martin, Isabel Martins, Chantal Pouliot,** and **Matthew Weinstein** introduces a fairly unique focus that deals with potential harms to various individuals, societies, and environments. As an example, they highlight the devastation from climate change linked to fossil fuel uses. Given apparent roles of many governments in supporting powerful problematic networks that involve fields of science and technology, many science educators recommend that school science should not only enlighten students about harms and encourage them to make logical personal decisions about associated controversies, but also prepare them to take sociopolitical actions that might contribute to their conceptions of a better world. The chapter then brings together international science education researchers to discuss their uses and analyses of a curriculum framework called "STEPWISE" which is intended to facilitate such critical and activist science education.

The final chapter in this part from **Judith S. Lederman, Norman G. Lederman, Selina L. Bartels**, and **Juan P. Jimanez** reports on a large-scale international project on students' learning of scientific inquiry during their elementary school

years. Eighteen countries or regions spanning six continents including over 2000 students participated in the study. The results overwhelmingly show that students around the world at the beginning of grade 7 have very little understanding about scientific inquiry. Some countries do show reasonable understanding in certain aspects but the overall picture of understanding of scientific inquiry is not what is hoped for after completing six years of elementary education in any country. Collectively, the studies reported highlight the need for innovation in science teaching and learning to ensure that future citizens are equipped with appropriate skills and identities in dealing with scientific and socioscientific issues.

Learning Progressions and Competences

The third section of the book includes six chapters that deal with a range of issues relating to learning progressions and competences. To enhance student learning and to develop appropriate learning sequences, various models of student learning have been proposed and discussed throughout the literature. In this section, student learning is examined through various contexts.

The area of Futures Studies, a research area which investigates "building the future" is the background for the chapter presented by the authors **Giulia Tasquier, Laura Branchetti,** and **Olivia Levrini.** They propose the use of science as the source of knowledge to develop future-scaffolding skills. Having developed and implemented a module on climate change with a group of second level students at a summer camp, the study was evaluated to determine students' perception of time (both present and future) and also to further define the future-scaffolding skills. Interestingly, the authors highlight that their most relevant finding from the analysis of the evaluation of the module was the sense of hope and calm expressed by the students on completion of the module, suggesting the role that science education can play in supporting young people in a world where there can be negativity about the future.

According to the authors **John Airey, Josefine Grundström Lindqvist,** and **Rebecca Lippmann Kung,** physicists can view the world using a web of equations that can be considered as the culmination of a range of actions, assumptions, and historical discoveries. However, how does the undergraduate student understand these equations and what does it mean to "understand an equation"? Using data from a study of undergraduates in three countries, the authors found similar interpretations in each country, which led them to suggest eight distinct themes with regard to students' understanding of a physics equation. Using these themes, they proposed a set of questions for students to ask themselves so that they can check their own understanding of what a particular physics equation represents. This work is continuing to determine if the expert opinion, i.e., from physics lecturers, on what it means to "understand an equation" agrees with that of the undergraduate student.

Studies on learning progressions that show the sequential development of student ideas have been used in a variety of contexts in the literature including design

of classroom activities, assessments and student ideas and thinking. The chapter by **Erin Marie Furtak** and **Kelsey Tayne** examines how a number of teacher communities used learning progressions to support the design of formative assessment tasks, including interpretation of student ideas and planning feedback. The authors discuss the work of the group involved and highlight the use of learning progressions to explore student ideas and setting learning goals by the group with less emphasis in using the learning progressions to interpret the student ideas and in identifying the next steps in the learning.

The development of models of student learning can influence and inform teaching strategies, curricula, and assessment practices. In the chapter presented by authors **Annette Upmeier zu Belzen, Alicia C. Alonzo, Moritz Krell,** and **Dirk Krüger**, they present the two approaches to model student learning, namely Learning Progressions and Competence Model. The chapter outlines the origin of the two models and draws comparisons between them. They conclude that while both models are valuable and worthwhile in their contribution to teaching and learning, the subtle differences between the approaches can be informative, particularly in terms of curriculum emphasis, and student achievement.

The process of learning was investigated in the chapter by **Eva Pennegård**, within the context of the physics classroom at lower second level. Using videotaped lessons, the teachers could discuss and reflect on their actions that facilitated learning by their students; using the same video lessons, the students involved also reflected on their learning and the teacher actions that facilitated their learning. Teachers were then able to reflect on the responses from the students in terms of their practice. The inclusion of the student voice was an important element for professional development of the teachers.

The final chapter in this section by authors **Anni Loukomies, Kalle Juuti, Jari Lavonen,** and **Katariina Salmela-Aro** emphasizes that the science-related competence beliefs of young students (in this study 7–8 years of age) can be increased by participation in science and technology workshops. In this study, the students were involved in three workshops—on electrical circuits, programming with Lego Mindstorm robots, and on computer-based data logging. It was argued that these workshops could be included in the main curriculum.

Enhancing Science Teacher Education

It is now widely acknowledged that the key to improving science education and successful curriculum development is the quality and involvement of science teachers. The same is true of science education research: instead of being done on teachers it is most effective if done with and by practicing science teachers. The failure to improve science teaching and learning, despite decades of science education research, is largely due to a failure to involve and resource science teachers, and to

make research findings available in an accessible and relevant form. The four chapters in this final section are all connected to science teacher education.

The chapter from authors **Irina Kudenko, Pauline Hoyle,** and **Ben Dunn** makes the case for subject-specific professional development (PD) in science for primary teachers in the UK. It compares two models of delivering such PD: through school-led PD partnerships and through external-led PD by primary STEM experts. This chapter is based on sizable data sets for each model and each provides evidence of improvement in teachers, schools, and pupils STEM experience, although each model has its weaknesses. The evidence presented shows that the two approaches are complementary and that the research has led to modifications in the programs, in a blended approach, tackling the weaknesses and drawing on the strengths of each model. It is good to see research actually changing practice as examined in this study.

Hannah Sevian and **Vesal Dini** use a design-based research (DBR) approach to evaluate the way experienced secondary chemistry teachers use formative assessment in their science teaching and to develop a Principled Practice Knowledge (PPR) resource. This chapter gives a clear description of a DBR approach to improving teachers' competence in using formative assessment (FA). It describes a 6-year project, conducted in four phases, which developed a PD resource to help teachers use FA more effectively. The focus on the importance of the teacher as the key player in the process is a significant conclusion. The chapter shows how DBR can used to create a useful, practical resource of Principled Practice Knowledge (PPK) to help teachers implement changes in practice.

The authors **Giannis Sgouros** and **Dimitris Stavrou** focus on developing teaching modules in Nanoscience and Nanotechnology (NST) in conjunction with secondary science teachers, science education researchers, communication experts, and subject experts in NST, as a Community of Learning (CoL). As well as introducing a new topic into school science, the modules also included aspects of Responsible Research and Innovation (RRI), in the context of the IRRESTIBLE project, and also out-of-school activities. The work is a good example of collaborative curriculum design and a key finding was the importance of teachers' reflection on their own professional practice.

Iztok Devetak, Sonja Posega Devetak, and **Tina Vesel Tajnšek** discuss how to develop the competences of pre-service teachers in managing students' allergies. This topic is somewhat outside the usual scope of science education and deals with an aspect of a teacher's professional responsibility for their students' welfare. The chapter describes a program to develop the medical competence of pre-service teachers in a classroom setting. It has no specific reference to science education but clearly the topic has a place within a science course, especially if we take chemical and biological sensitivities into account.

All these four, very different, chapters highlight the importance of the teacher in the classroom and their interaction with their students but also with the wider educational community and society.

Concluding Remarks

As the reader can see, this volume deals with a wide variety of topics and research approaches, conducted in various contexts and settings, all contributing to our shared knowledge of science education. As the editors, we trust this volume will invoke discussion and ignite further interest in developing new collaborative research studies, practices, and policy in Science Education.

The internet and other digital applications and media make it possible, feasible, and attractive to organize collaborative international research groups that can jointly carry out science education research from physically distant locations. The ESERA biennial conference provides an outstanding forum for science education researchers and practitioners to present their research and expose it for discussion and examination, and further build their networks—not only within Europe but all over the world. We want to extend a sincere thank you to the ESERA Board for the opportunity and for the confidence bestowed on us to enable us to host a successful ESERA 2017 Conference in Dublin, Ireland.

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Contents

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About the Editors

Eilish McLoughlin is Associate Professor in the School of Physical Sciences and Director of the Research Centre for the Advancement of STEM Teaching and Learning (CASTeL) at Dublin City University. She received her PhD in Experimental Surface Physics in 2000. Her research interests are focussed on the development of curriculum, instruction, and assessment models in Physics/STEM education, at all levels of education, from primary school to PhD level. She has led and collaborated on many research projects at EU, national, and local levels, including coordination of EU FP-7 project ESTABLISH and partner in EU projects 3DIPhE, OSOS and SAILS. She co-leads the physics initial teacher education program at Dublin City University and has led several projects that support teachers, both in-service and pre-service, in adopting innovative practices in their classrooms and enhance student identity in Physics. She has received recognition for her leadership in STEM Education and engagement across formal and informal contexts, including the NAIRTL National Award for Teaching Excellence (2010), Institute of Physics Lise Meitner Medal (2018), Institute of Physics Young Professional Physicist of the Year (2006), and Dublin City University's President Awards for Public Engagement (2017) and for Teaching and Learning (2005).

Odilla E. Finlayson is Associate Professor of Science Education in the School of Chemical Sciences at Dublin City University. She is one of the founding members of CASTeL (Centre for the Advancement of STEM Teaching and Learning) in Dublin City University and plays an active part in its management and development. She is involved in teaching (mainly physical) chemistry to undergraduate science students and to pre-service teachers. She is interested in curriculum development at second level and was a member of the Board of Science Studies in NCCA (National Council for Curriculum and Assessment). She sits on the Council of the Institute of Chemistry of Ireland, where she is Registrar and also convenor of the Education Committee. Her current research interests are in sustaining science across

transitions and in particular in development of appropriate science (chemistry) curricula and assessment. She is also involved in co-ordinating Ireland's involvement in science Olympiads, namely International Junior Science Olympiad, European Union Science Olympiad and the International Chemistry Olympiad, as Country Co-ordinator and mentor. She has been involved in many local and international research projects, including EU FP-7 project ESTABLISH and co-ordinator of EU FP-7 project SAILS.

Sibel Erduran is Professor of Science Education at University of Oxford and a Fellow of St Cross College. She also holds Visiting Professorship positions at University of Oslo, Norway and Zhejiang Normal University, China. She is an Editor for *International Journal of Science Education,* Section Editor for *Science Education*, and serves on the Executive Board of European Science Education Research Association. Her work experience includes positions in the USA (University of Pittsburgh), Ireland (University of Limerick) as well as other universities in the UK (King's College London and University of Bristol). Previously she held Visiting Professorships at Oxford Brookes University; National Taiwan Normal University; Kristianstad University, Sweden; and Bogazici University, Turkey. Her higher education was completed in the USA at Vanderbilt (PhD, Science Education and Philosophy), Cornell (MSc, Food chemistry and Chemistry), and Northwestern (BA, Biochemistry) Universities. She has worked as a chemistry teacher in a high school in Northern Cyprus. Her research interests focus on the infusion of epistemic practices of science in science education, in particular chemistry education. Her work has received international recognition through awards from NARST and EASE. She is currently the Principal Investigator of projects funded by the Wellcome Trust and Templeton World Charity Foundation. Her edited book on *Argumentation in Chemistry Education: Research, Policy and Practice* (Royal Society of Chemistry) and co-authored book on *Transforming Teacher Education through the Epistemic Core of Chemistry: Empirical Evidence and Practical Strategies* (Springer) were published in 2019.

Peter E. Childs has been involved in the work of EPI-STEM, the National Centre for Science Education at the University of Limerick, since its inception in 2008. After reading Chemistry at Oxford (1965) and completing a DPhil in Solid State Chemistry (1967), he spent 2 years in North Western University on a postdoctoral fellow with a Fulbright scholarship. He then spent 6 years teaching chemistry from 1970 at Makerere University, Kampala, Uganda, where he became interested in working with teachers to improve school chemical education. Returning to the UK he had one year each at York and Leeds on research fellowships, before coming to Ireland in 1978. Initially, he taught chemistry and chemical education at Thomond College of Education to intending second-level teachers, and in 1990 joined the chemistry department in the University of Limerick, when the two institutions merged. He then taught inorganic and environmental chemistry, and worked with intending chemistry teachers, until 2009 when he retired. Since he began his retirement he has directed the Chemistry Education Research Group and been involved in three EU-funded projects: SALiS, a Tempus project (2010–2012); TEMI, an FP7 project,

2013–2016; ARTIST, an Erasmus+ project, 2017–2019. He has worked intensively with chemistry teachers since coming to Ireland; he started the magazine Chemistry *in Action!* in 1980, the ChemEd-Ireland conferences in 1982, and the Chemistry Demonstration Workshops in 2004, as well as running many in-service courses and workshops and industry study tours. A number of people have gained PhDs and Master's in science/chemical education under his supervision. He is past Chair of the EuCheMS Division of Chemical Education, and Past-President of the Irish Science Teachers Association and of the Institute of Chemistry of Ireland. His work in chemical education has been recognized by the BP Science Educator of the year award by the ISTA, the Boyle-Higgins Gold Medal of the Institute of Chemistry of Ireland, and an education award from Pharmachemical Ireland. In addition to chemical education he is also interested in the history of chemistry, the chemical industry, and science education.

Contributors

John Airey is a senior lecturer in Science Education at Stockholm University and a Reader in Physics Education at Uppsala University. John's research interests focus on disciplinary learning and its relationship to language and other semiotic resources.

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Nuria Álvaro is a PhD student in the Department of Didactics of Experimental Sciences of the Universitat de València, Spain. She holds a master's degree in secondary education teaching and a master's degree in education research. Her research concerns environmental health and environmental education. She is a secondary biology teacher in Catalonia.

Julia Arnold studied Biology and English for secondary education. After her PhD in biology education at Kassel University, she has been a post-doctoral researcher at RWTH Aachen University and at the Leibniz Institute for Science and Mathematics Education in Kiel, Germany. She is currently the head of the research group Biology Education at the Centre for Science and Technology Education, University of Applied Sciences and Arts Northwestern Switzerland – School of Education in Switzerland. Her main research interests are in health education and inquiry learning. She is particularly interested in the knowledge and motivational factors in these fields.

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Selina L. Bartels is currently an Assistant Professor at Valparaiso University. At VU, she serves in the role of science teacher educator where her course load is predominately teaching preservice teachers' science methods courses including grade levels, early childhood, elementary, middle, and secondary. Dr. Bartels' undergraduate degree is from Northern Illinois University where she studied elementary education; she then went on to earn both a master's and a PhD at Illinois Institute of Technology where she studied Philosophy of Science Education. Dr. Bartels spent a decade teaching in Chicago Public schools where she taught various grade levels and content areas. Dr. Bartels has presented her research at many local, national and international conferences. She also has several publications in various research and practitioners' journals and books.

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Part I
Innovative Approaches to School Science

Science Education: A Balancing Act Between Research in University, Daily Instruction in Schools, and Politics in Education Ministries

Peter Labudde (ORCID)

Introduction

"Research, practice and collaboration in science education" was the theme of the 12th European Science Education and Research Association (ESERA) conference held in Dublin in August 2017. Within this theme several questions arise, questions to which our scientific community should respond. For example, what are the advantages, but also what are the limitations of different approaches in science education research? How strong could and should be the relationship between research and daily school practice? With whom do we have to cooperate, in order to grasp both the needs of teachers and schools and the demands of research and politics, as well as to incorporate research into practice?

Questions like these provide the framework to much of our daily work. They have to be answered by each researcher for himself or herself, by a group of science educators, e.g. by a research group in a university, and by our scientific community as a whole. There is not just one answer to each question; instead, there are many of them. Each person and each generation of researchers have to answer the questions, again and again, a never ending, but always challenging task.

One reason for the challenge is to find a balance both between research and daily school practice and between research and educational policy. For example, on one side the colleagues in science departments and the governing boards of universities ask for more research projects funded by national science foundations, for more peer-reviewed international publications and talks, and for a high citation index and h-factor; to achieve all this, a science educator has to be engaged mostly in basic research. On the other side, teacher students, teachers, schools, and policy makers

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ask for a teacher training with a lot of examples and recipes for daily instruction; they ask for more developmental projects that respond to the needs of schools; to achieve this a science educator has to be engaged mostly in teacher training, professional development, and action research. How can one find a balance between these different and partly conflicting demands?

The questions mentioned in the first paragraph of the introduction also correspond to the aims of the ESERA organization, in particular the first and fourth aim:

(i) Enhance the range and quality of research and research training in science education in Europe.
(ii) Provide a forum for collaboration in science education research between European countries.
(iii) Represent the professional interests of science education researchers in Europe.
(iv) Seek to relate research to the policy and practice of science education in Europe.
(v) Foster links between science education researchers in Europe and similar communities.

In this contribution[1], I discuss the questions introduced above and try to provide some answers through discussing eight foci and notions. The eight foci are discussed in two parts, with each part presenting a different context.

(A) **Science education research** – in the context of school practice and education authority policy or in other words "from science education to practice and authorities":

　　1. Developing concepts for instruction
　　2. Responding to the needs of schools
　　3. Connecting researchers, teachers, and stakeholders
　　4. Implementing research results into practice

(B) **School practice and education authority policy** – in the context of science education research or in other words "from practice and authorities to science education":

　　5. Reframing recent scientific research as science content for schools
　　6. Considering non-formal teaching-learning processes
　　7. Helping to create curricular and structural changes
　　8. Being aware of his/her own responsibilities

Each of the foci and notions is explained from the perspective of science education and illustrated by using examples from specific research and development projects.

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[1] This contribution is based on my keynote at the ESERA 2017 Conference in Dublin (August 21–25, 2017).

Focus 1: Developing Concepts for Instruction

"Developing, implementing, and evaluating – together with teachers – concepts, materials, and units for instruction" is the first focus and notion. It corresponds to the fourth aim of the ESERA organization, i.e. "Seek to relate research to the practice of science education". Many colleagues in our scientific community are engaged in developing, implementing, and evaluating teaching units, materials, and concepts for daily instruction, either at regional, national, or international level. Two characteristics of this focus are particularly important: first, the cooperation of science educators and science teachers during all phases of this development and, second, the scientific evaluation of these units, materials, and concepts.

Example MobiLab

The project "MobiLab" (2018) from my research group may serve as a paradigmatic example for this first principle. Science educators and teachers developed a total of 150 experiments for students in grades 4–6. Many of these experiments are hands-on activities. The experiments are presented in nine themes: acoustics, air, electricity, energy, magnetism, microscope, optics, substances, and water. For each of the nine themes, three to five of the central questions of the experiment focus on main phenomena. For example, in the theme air, these questions are the following: (1) Is it possible to see, feel, or hear air? (2) Is air really nothing? (3) Does air have a force? (4) Of what is air composed? Pupils attempt to answer these questions by performing experiments, with about four experiments associated with each question. Some of the experiments are given in a cookbook style, while others use an inquiry-based learning approach. The pupils perform the experiments, describe and explain them in their "research journals", and discuss questions and results with other pupils in small groups or in the whole class. Further characteristics of the MobiLab are:

- The target audience includes both grade 4–6 pupils and their teachers; for pupils, it is expected that MobiLab opens new ways for them to engage with science and increase their interest in science; for teachers, MobiLab should help to develop and improve their pedagogical content knowledge and self-confidence in science instruction.
- Almost all materials used are everyday items, i.e. pupils can perform the experiments at home and show the phenomena to their friends and parents.
- Physically, the MobiLab is a small van with 150 experiments contained in more than 150 boxes, and many of the experiments are available in multiple copies.
- Teachers and/or schools can order the MobiLab for half a day or for several days. Normally a teacher orders the MobiLab for half a day for a specific theme, e.g. the pupils of her/his class explore the main phenomena and properties of air in 3–4 h.

- A member of the MobiLab team, i.e. a primary school teacher with a background in science education, drives the MobiLab to the school and works with the pupils – in cooperation with the teacher of the class.
- The MobiLab team offers half-day courses to teachers and schools. Typical courses are "Introduction to the MobiLab", "Hands-on activities with water", and "How to build up a 'research lab' in primary schools?" Teachers are only allowed to order the MobiLab after they have attended the course "Introduction to the MobiLab".

An independent researcher with a strong background in evaluation and qualitative and quantitative methods has evaluated the MobiLab over a 2-year period. The researcher gathered data using questionnaires, interviews, and videos (Holmeier et al. 2016). The findings of this study were very positive, i.e. the pupils and even more the teachers state that they have learnt much; they have developed their interest in science and would order the MobiLab again. Therefore, it is not a surprise that the number of visits of the MobiLab in schools increased from 30 half-days in the first year (2013) to more than 120 visits in 2017.

Résumé The features of the first focus have been illustrated in the MobiLab project – strong relationship to classroom practice, development in collaboration with teachers, and careful and independent evaluation. Two comments on the project are important in regard to the "balancing act" in the title: First, it is a typical development project; teachers, schools, pupils, and policy makers appreciate a project like this; but as a researcher who is involved in this project, one cannot improve his/her citation index. Second, in many development projects, the evaluation is missing; but in order to find a balance between development and research, it seems necessary to me to evaluate a project that, e.g. deals with a science lab, with teaching development (see focus 2) or implementing research results into practice (focus 4).

Focus 2: Responding to the Needs of Schools

"Analysing the needs of teachers and schools: initiating, implementing, and evaluating teaching and school development". This second issue focuses on the needs of teachers and schools. What are the challenges in science education for these? What do they want to improve in their daily instruction or in their school? Finding answers to questions like these and implementing solutions in schools demand for in-service professional development and action research to be carried out. The European Commission (2015) postulates "the quality of teaching, teacher induction, preservice preparation, and in-service professional development should be enhanced to improve the depth and quality of learning outcomes". The report asks for improvements at all levels and at all phases of teacher education programmes and in particular in-service professional development. But, how far is a national educational system and its stakeholders and how far is our community substantially engaged in in-service professional development?

Example SWiSE

The project SWiSE (2018, Swiss Science Education) is an almost nationwide project in Switzerland. For the pupils, the main objectives are to offer children and young people access to science and technology that is appropriate for their age, to promote self-organized learning and to explore and implement new pathways in competence-oriented education. With regard to the teachers and the schools, the objectives are to reflect and further develop science and technology education according to the local needs, to exchange experiences among schools and to build networks. The project team consists of science educators from eight universities and teachers colleges, two institutions specialized in in-service professional development and the Swiss Science Centre Technorama. The institutions called for applications from schools to become a so-called SWiSE school for a period of 3 years. A SWiSE school obligates oneself to engage in a school-specific developmental project based on its needs, to delegate two so-called SWiSE teachers to initiate and implement the project in collaboration with the SWiSE team and the science teachers in the school. What does the SWiSE team offer to the schools?

- The reduction of the teaching load of the two SWiSE teachers by one period per week during 3 years; foundations and cantonal education ministries financed this reduction.
- Mentoring of the two SWiSE teachers in a school by an expert of the SWiSE team.
- Regional and interregional network meetings.
- Modules for continuous teacher professional development.
- Participation at the annual conference «SWiSE-Innovation».
- In-school coaching and training.
- A programme in order to get a Certificate of Advanced Studies (CAS, 10 credit points) in science education.

After 3 years of collaboration, science educators and teachers published three books on good practice examples of SWiSE (Stübi et al. 2017), science education concepts applied in SWiSE (Metzger et al. 2016), and the evaluation of SWiSE (Koch et al. 2016). Although aspects of the project have been reduced due to financial restrictions, SWiSE is still going on, e.g. the annual conference "SWiSE-Innovation", workshops for teachers, and summer schools for science educators.

Résumé Although researchers have initiated SWiSE, the project is based on the needs of schools (and on science education findings). It focuses on cooperation and networking, and it involves teachers, school managers, and other stakeholders. If our scientific community wants to respond to the needs of schools and teachers, we have – of course – to collaborate with them. We must resist and fight against the opinion I have heard from colleagues of universities like scientists, pedagogues, and even science educators saying that this kind of work is "dirty", not as "clean" as lab work and "real" research.

Focus 3: Connecting Researchers, Teachers, and Stakeholders

"Connecting and integrating researchers, teachers, and stakeholders – from the beginning" is a focus that goes well with the fourth aim of the ESERA, i.e. to "seek to relate research to the policy and practice of science education in Europe". It also fits the theme of the ESERA 2017 conference "Research, practice and collaboration in science education". Science educators are responsible for this connecting and integrating. It is their obligation to deliver their knowledge to teachers and stakeholders and vice versa; there is the obligation on teachers and stakeholders to collect the results of research in science education.

Example ASSIST-ME (Assess Inquiry in Science, Technology, and Mathematics Education)

The European Union financed this project (2013–2016) within the seventh European Framework Program. The project had two general aims:

- Development and implementation of formative and summative assessment methods that are suitable for inquiry-based learning in science, technology, and mathematics (STM)
- Elaboration of guidelines for policy makers and other stakeholders to ensure that assessment enhances inquiry-based learning in STM

Based on an analysis of what was known about summative and formative assessment of knowledge, skills, and attitudes, the project designed a range of combined assessment methods. These methods were tested in primary and secondary schools in different educational cultures and contexts across Europe. Nine universities across eight countries participated in the project with the University of Copenhagen as the coordinating institution (ASSIST-ME 2016). The twofold aim of the project, i.e. the development of assessment methods for daily practice and the elaboration of guidelines for policy makers and other stakeholders, made it necessary to collaborate with teachers and stakeholders – from the beginning of the project. This is why in each of the eight participating countries, a so-called Local Working Group, i.e. a group of about 20 teachers, and a so-called National Stakeholder Panel, i.e. a group of about 10 stakeholders, were set up. The teachers came from the vicinity of each University to form the Local Working Groups. The stakeholders, including policy makers, school-inspectors, experts for the development of curricula, unionists, and researchers, came from across the nation and formed the National Stakeholder Panel. The international research team presented the results of the project online for the three different communities that engaged in the project (ASSIST-ME 2016). The project team stated that the information presented on the project website allowed:

- "Teachers to develop effective combinations of formative and summative assessment in daily practice in primary and secondary schools

- Researchers to study formative and summative assessment methodologies and practices in different educational systems
- Policy makers to inform decision-making on curriculum design, teacher training, and assessment strategies at institutional, regional, and national levels taking into account relevant system characteristics and variables."

Résumé   ASSIST-ME is a paradigmatic example of research in (science) education as an interdisciplinary and transdisciplinary venture: interdisciplinary in the sense that different disciplines, like biology, chemistry, mathematics, science, and technology education plus cognitive psychology, statistics, and educational policy, were part of the project, and transdisciplinary in the sense that on one side, science educators and teachers and, on the other side, policy makers participated in the project, i.e. research and politics, were connected (for other examples see foci 7 and 8). Without this connection, research and development often remain ineffective.

Focus 4: Implementing Research Results into Practice

"Grasping the demands of research and implementing them in projects that are oriented towards daily school practice". I distinguish between the needs of schools, see, e.g. focus 2, and the demands of research. Typically, the needs of schools and teachers are (new) materials for the laboratory, new concepts for science teaching in the kindergarten, improved content knowledge for primary school teachers, and ideas for interdisciplinary science units. Typically, the demands of science education research are the improvement of teaching-learning processes, including conceptual changes, the analysis of the quality of instruction in physics (Fischer et al. 2014), and the development of general concepts like scientific literacy or the development of new formats for large-scale assessments. The claim of the fourth focus is that when grasping the demands of research and/or doing so-called fundamental research, relate it to daily classroom practice and cooperate with teachers.

Example Diagnostic Instruments

Over the last 30 years, the development of instruments for formative and summative assessment has become an important issue. These instruments are needed for the individual diagnosis of students' competences and for giving them feedback on their learning. They are also needed for large-scale assessments like PISA (Programme for International Student Assessment) and nationwide tests. Therefore, both, researchers and policy makers, are interested in new instruments. Von Arx and Korsak (2014) initiated a project that was funded by the Swiss National Science Foundation. The focus of their study was to address the research question: Are tests with concept map problems and/or multiple-choice problems suitable to measure – in a valid and reliable manner – competences in regard to ordering, structuring, and

modelling? This question is typical in fundamental research, because it is driven mainly by the demands of the research. The roots of the project were not in daily instruction, nor did the project fit the main needs of teachers or schools. However, from the perspective of science education research, it is interesting. The two researchers developed a model for the assessment of competences in relation to ordering, structuring, and modelling; they developed suitable instruments with multiple-choice and concept map problems, questionnaires, and interview questions; they analysed the data using sophisticated statistical methods – and their results showed that the instruments were suitable to measure the competences in a valid and reliable manner. Although this project was fundamental research, it has been related to daily instruction and science teacher education:

- Chemical substances and reactions as the content of the tests
- Tests in 25 classes (grade 9)
- Teacher training and continuous professional development
- Publications in journals addressing teachers

Résumé   Balancing the needs of schools and the demands of research is a challenge for all science educators. Projects that focus on fundamental research questions like the development of new assessment instruments should be aligned as closely as possible to daily practice. The development of multiple-choice and concept map problems to assess competences in ordering, structuring, and modelling showed different ways of how to do this. One of the ways is the collaboration with teachers. It is important not only when responding to the needs of schools (focus 2) but also when implementing research results into practice.

The foci 1–4, described and illustrated above, belong to the part I "from science education to practice and authorities" of the eight foci discussed in this chapter. The following foci 5–8 belong to part II "from practice and authorities to science education". This part is focussed on when practice and authorities take their questions to science educators. I use practice and authorities as an overall term that includes not only teachers, schools, inspectors, policy makers, and education ministries but also institutions like museums, mass media, and science laboratories.

Focus 5: Reframing Recent Scientific Research as Science Content for Schools

"Reframing recent research in biology, chemistry, and physics as science content for schools: A major task for science education". Tens of thousands of scientists all over the world are engaged in research. The knowledge in biology, chemistry, physics, and in other disciplines like astronomy, agriculture, material science, or climate science is still exploding. Some of this new knowledge should become part of the science curricula – but it needs to be reframed for instruction. The reframing is a major task of science educators.

Example Nanoscience

In the last 20 years, nanoscience has become a major interdisciplinary research focus in biology, chemistry, physics, and other disciplines. Due to the importance and success of this research and its results, many science education groups have developed teaching concepts, units, and materials, in order to bring nanoscience to schools. A typical example is the EU-Comenius project "Quantum Spinoff". The aim of the project was to bring science teachers and their students of grades 11–12 into direct contact with research and entrepreneurship in nanoscience. In this way, the project wanted to educate a new generation of scientifically literate European citizens and inspire young people to choose science and technology careers (Quantum Spinoff 2014). During the project, authentic inquiry activities were developed and implemented, which enabled students to:

- Come in contact and understand the basic insights of quantum physics and nanoscience
- Interact with researchers who develop applications based on scientific results
- Interact with entrepreneurs doing business based on these applications
- Develop their own virtual product or service based on the studied technologies and present it like real scientists to a jury of experts and to a public audience of students just like themselves

About 30 teachers and classes of grades 11–12 from 4 different countries participated in this project. During an international summer school and in their own schools, the teachers developed teaching units of 6 to 12 periods, planned visits, and cooperation with research institutions and high-tech companies and created opportunities for their students to develop their own virtual spinoff product or service.

Résumé Nanoscience is a paradigmatic example of reframing recent research for instruction in the upper secondary level. Furthermore, the project Quantum Spinoff has features that make it paradigmatic in different ways. The project is international, it is interdisciplinary (including entrepreneurship and economics), and it links practice, science education, science, and industry. For many scientists, the reframing of recent research for instruction is the most important and – sometimes – only task of science education. I agree that it is important, but it is definitely not the only task of science education.

Focus 6: Considering Non-formal Teaching-Learning Processes

"Considering non-formal and informal teaching-learning-processes as domains for research and development" is an issue that aligns with the focus of the ESERA 2017 conference. The organizers claim, "the theme of the conference – research, practice, and collaboration in science education – underlines aspects of great relevance in contemporary science education research: the need to reflect on different approaches

to enhancing our knowledge of learning processes and the role of context, designed or circumstantial, formal or non-formal, in learning and instruction". The focus of science education research should not only be on formal learning and instruction, i.e. in schools, it should also focus on non-formal and informal learning and instruction, such as in science museums, outdoors, or on the television.

Example the TV programme Quarx

In 2015, the Swiss Radio and Television (Schweizer Radio und Fernsehen (SRF)) asked our research team to develop teaching materials in German for the international TV programme Quarx (2015), a series of 26 episodes of about 5 min each, produced by the BBC for the school television. The SRF sent a description for the programme, a trailer (Quarx 2015), and the titles of the 26 episodes. The brief description of the producer says: "Quarx is a madcap series of scripted films for kids. Have you ever wondered what would happen if we could change the laws of physics? Watch this and find out. But we warn you – it isn't pretty. From a pet black hole that goes out of control to a world overrun with giant insects, the Quarx lurch from the brink of one apocalypse to another". Our research team decided to accept the challenge of developing teaching materials for a TV programme that is so different to daily formal instruction and learning at schools. For each of the 26 episodes, the team developed teaching notes of about two to four pages, including learning objectives, links to the curriculum, and lesson planning. Furthermore, two to four pages of background information, i.e. the underlying physics, chemistry, biology, and engineering (SRF 2017), was developed. Like the authors of a textbook, the team developed teaching materials, based on the TV episodes and based on their knowledge of science and science education. One aspect that was missing from this project was the evaluation of the episodes and the materials.

Résumé   Writing teaching materials for a TV series proved to be a venture of many challenges and joys. It offered the chance to reflect on formal education from the viewpoint of non-formal education, and it can broaden the horizon in regard to media and their use in science instruction. Most of the research projects of the ESERA community focus on formal education in schools. A shift to more projects focussing on non-formal or informal teaching-learning processes could "enhance the range and quality of research and research training in science education", as stated as the first aim of the ESERA association (see the introduction of this contribution).

Focus 7: Helping to Create Curricular and Structural Changes

"Creating and supporting curricular and structural changes that have been initiated by politics – looking for and cultivating the cooperation and partnership with authorities, parliaments, and other institutions". At least once per generation, i.e. almost every 20 years, policy makers and other stakeholders, e.g. teachers, unionists, parents associations, and researchers, initiate and develop new curricula and sometimes even new school structures. This is a normal and necessary process, because changes in society, values, knowledge, methods, information, and communication technologies demand for new curricula. Science educators should be part of these teams that develop new curricular and/or new teaching materials.

Example Curriculum STEM

The two cantons Basel-Stadt and Basel-Landschaft are just introducing a new curriculum K-9 in Switzerland. This curriculum includes common subjects like mathematics and nature and technology. The policy makers of the two cantons decided to offer compulsory optional subjects in grades 8 and 9 with two periods per week. These compulsory optional subjects are STEM (science, technology, engineering, and mathematics), Latin Language and Culture, Italian Language and Culture, Art and Design, Technology and Design, and Music. It should be noted that pupils who choose STEM as a compulsory optional subject have already taken the common subjects mathematics and nature and technology. Therefore, the curriculum of the subject STEM must go further than the curricula of mathematics and nature and technology. On behalf of the policy makers, a team of science educators from our university and science teachers developed the STEM curriculum, teaching units and materials, teaching notes, and background information. The curriculum comprises of 8 interdisciplinary topics, i.e. 8 units of about 16 periods each (Basel-Stadt 2017): micro-cosmos, water wheel, energy makes mobile, from the binary system to the paper plane, creative cascade, a view to the sky, robotics, and noise pollution. Each topic includes several parts, e.g. (1) creating a noise map with a smartphone, (2) what GPS is and how does it function, (3) interpretation of noise maps and conclusions, and (4) protection against noise and the psychology of noise.

Résumé Similar to the examples discussed in foci 1, 2, 3, and 5, science educators and teachers have worked together to develop new teaching units, materials, and curricula. In this case, however the collaboration was not initiated by science educators, teachers, or scientists but by policy makers. Science educators have counselled and collaborated with the politicians and administrators. The science educators were both critical friends and supportive, loyal, and cooperative experts. It is a good example of transdisciplinarity, as described in the résumé of focus 4.

Focus 8: Being Aware of His/Her Own Responsibilities

"Being aware of his/her own responsibility with regard to science and society". Researchers have always taken on responsibility, e.g. the responsibility to perform research in an honest and ethical manner or the responsibility to inform other stakeholders about possible positive and negative consequences of their research and its results. For researchers in genetics, medicine, or nuclear physics, the focus of being aware of his/her own responsibility seems to be obvious, but has this been made explicit for science educators? On the website of the ESERA association (www. esera.org), the word responsibility is missing.

Example Competence Models, Standards, and Monitoring

Triggered by PISA (Programme for International Student Assessment), over the past 20 years, several countries have developed new competence models, standards, monitoring systems, and nationwide tests (Waddington et al. 2007). Switzerland has also developed national standards (EDK 2011), new curricula, and a nationwide monitoring system. For a nation that did not use any nationwide test up until then and where the educational system is highly decentralized, the introduction of standards and monitoring were quite a revolution. The four cantons of Northwestern Switzerland went even further and introduced cantonal examinations, so-called checks, at the end of grade 3 (only mathematics and German) and grades 6, 8, and 9 in mathematics, German, French, English, and Science. The checks were a summative assessment, where a mark of check 9 is part of the final report at the end of grade 9 (Kanton Aargau 2013).

Science educators developed the checks in science on behalf of the four cantonal ministries of education. In collaboration with policy makers and teachers, the science educators had to address questions such as "Which competences should (and could) be tested? What should be the content of the problems? Which test methods can be used? What signals do we want to send to teachers, pupils, parents, and other stakeholders?" Science educators had a significant responsibility in addressing these questions. In Northwestern Switzerland, the educators decided on the following types of checks in science: firstly, the pupils, working in small groups, had to perform a laboratory experiment of 45–60 min in either biology, chemistry, or physics. A choice of three experiments was given to the science teacher, and he/she chose one of them for his/her class. The experiments were common investigations, e.g. measuring and analysing a person's heart rate during different activities and measuring and calculating currents and potential differences in electric circuits. Secondly, the pupils answered an online adaptive test, i.e. the check. This online test included two types of problems relating to the experiment that the pupil had just performed several problems on different topics in biology, chemistry, and physics. The checks were evaluated, not only by examining the results of the tests but also through the use of questionnaires and interviews with the teachers.

Résumé The check emphasizes, by its specific format, the importance of experiments in science education, i.e. firstly doing a laboratory experiment and then completing an online test relating to the experiment and other science topics. This approach gives a clear message to pupils, teachers, parents, curriculum developers, and textbook authors. The developers of these checks, which include science educators, make the decision on what type of check is used and take a lot of responsibility for this decision. They determine what type of science instruction and what type of scientific literacy in their country. However, are these developers aware of this significant responsibility?

Conclusion

In my keynote at the ESERA 2017 conference and correspondingly in this chapter, I described and illustrated science education as a balancing act between research in university, daily instruction in schools, and politics in education ministries. As researchers in science education, we should ask ourselves, what is the range and what are typical features of our research? How far and in what way do we relate our research to the policy and practice of science education? Do schools and authorities come with their needs to us and – vice versa – do we impart and pass on our research to schools and authorities?

One could ask why it is a balancing act for a single person and why it is not for our scientific community as a whole. The following reflections and conclusions are explicitly stated as *black and white*, but the reality is much more differentiated.

For the individual, i.e. for a PhD-student, a post-doc or a professor, it is of big relevance if she/he:

  (i) Is engaged in teaching and school development and by this appreciated and accepted by teachers, principals, and policy makers *or* is engaged in basic research funded by the national science foundation and by this appreciated and accepted by the colleagues of the science department and the governing board of the university

 (ii) Has broad and long experience in teaching science at different school levels and has by this the right pedigree *or* has a broad and long experience in research including sophisticated designs, instruments, and analyses and has by this the right pedigree for many university people

(iii) Collaborates just with teachers students, teachers, and schools and is therefore a colleague of these *or* collaborates just with scientists, psychologists, educators, and psychometrists and is therefore a colleague of those

(iv) Is a critical friend and colleague of policy makers and by this – in some sense – doing effective research and development *or* does not have any contact with policy makers and is by this independent but, to a certain degree, ineffective

For the scientific community of science educators, it is of big relevance if their research:

(v) Is based on the needs of teachers and schools *or* on the demands of research and of the scientific community: Which are the "forces" and "currents" pushing their research forward?

(vi) Is published and discussed in journals and conferences just for teachers *or* in journals and conferences just for researchers: For whom does the community publish? What are the criteria for "good" research?

(vii) Is situated in a science department *or* in a school of education: What is the institutional frame of the research? How are the members of the community and the community itself socialized?

The seven reflections and conclusions, i. to vii., is *explicitly* black-white painting. I hope that the eight foci, 1 to 8, with their illustrative examples can be a base for more sophisticated answers, answers given by the individual and by the community.

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History and Philosophy of Science: A Lever to Teach Energy at High School

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Learning Difficulties and Issues

Energy is both a fundamental concept of physics and a major component of current socio-scientific issues. Accordingly, this concept lies at the core of the science curricula in numerous countries (Lee and Liu 2010; Eisenkraft et al. 2014). For instance, in the USA energy is considered as a "crosscutting concept" which helps to "organize" the "disciplinary core ideas" (NGSS Lead States 2013). However, understanding this concept is far from obvious. Energy does not depict a particular phenomenon but can be applied to a wide range of phenomena in all branches of physics; it is therefore very abstract (Warren 1982; Millar 2005). Although a definition of energy is available, namely, the one proposed by Rankine (see below), this definition remains disputed and is not always introduced in classrooms; often, energy is defined merely as a conserved quantity (Bächtold 2018). As a matter of fact, students develop a variety of erroneous conceptions (Watts 1983; Duit 1984; Gilbert and Pope 1986; Trumper 1993). Moreover, energy is embedded in a highly complex conceptual network: first, energy has several associated sub-concepts, such as the sources, forms and modes of transfer of energy; second, it is closely related to other quantities, such as force, temperature or power. As a consequence, students tend to make several kinds of confusions: e.g. they often wrongly consider work and heat as forms of energy (Cotignola et al. 2002; Jewett 2008); they tend to confuse energy and force (Watts 1983; Trellu and Toussaint 1986) or heat and temperature (Lewis and Linn 1994; Harrison et al. 1999). Finally, the principle of energy conservation is very difficult to master (Driver and Warrington 1985; Solomon 1985; Trumper 1990; Neumann et al. 2013). To apply it accurately, students need

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first to master the ideas of energy transformation and transfer; they also have to understand the notion of dissipation (Duit 1984; Solomon 1985; Lacy et al. 2014), and they must be able to identify the relevant system and distinguish it from its environment (Arons 1999; Van Huis and van den Berg 1993). As a consequence of all these learning difficulties, teaching energy appears to be a great challenge. Since the 1980s, several teaching strategies have been proposed (for a review, see Millar 2005; Doménech et al. 2007). Some of them are opposed, e.g. either for or against introducing the notion of energy transformation (Nordine et al. 2011; Falk et al. 1983; Brewe 2011) and either for or against introducing energy as a "quasi-material substance" (Duit 1987; Colonnese et al. 2012). However, no systematic empirical comparison between the proposed strategies has been performed yet. Nonetheless, a "learning progression" of energy has been identified, thanks to several empirical studies (Liu and McKeough 2005; Lee and Liu 2010; Nordine et al. 2011; Neumann et al. 2013): first, students tend to master several forms and sources of energy, then the notions of energy transformation and transfer and eventually the notion of dissipation and the conservation principle. These outcomes supply landmarks for organizing a teaching programme for energy throughout schooling. However, the following question remains: what specific teaching strategies should be developed at each stage of the learning progression so as to help students to overcome their difficulties and acquire a deeper understanding of energy?

The Contribution of History and Philosophy of Science

Several authors have highlighted the interest of history and philosophy of science (HPS) for the teaching of energy (De Berg 1997; Cotignola et al. 2002; Coelho 2009; Rizaki and Kokkotas 2013; Papadouris and Constantinou 2016; Lehavi and Bat-Sheva 2018). On the one hand, HPS can provide an accurate insight into the meaning of the concept of energy and help to conceive relevant teaching sequences. For instance, based on a "historiographical analysis" of the concept which puts forward the "causal and the unifying characters of energy", Rizaki and Kokkotas (2013) developed an original teaching approach for primary school. On the other hand, some elements of HPS can be introduced directly into the classroom. For instance, some historical experiments can be presented to students; following de Berg (1997), we consider that the historical reconstruction designed for the classroom can omit some experimental or mathematical details; what matters is to present the historical context and in particular the scientific problems, which enable students to understand why the scientists performed their experiments and how they could interpret the outcomes.

Research Questions

In line with the authors cited above, we undertook a collaborative work with teachers to build a new teaching strategy for energy at high school which relies on HPS. In this study, we aim at investigating the usefulness of HPS and more specifically the two following research questions: (i) Does a collaborative work aimed at introducing HPS in the teaching of energy help high school physics teachers to understand the issues of energy teaching and change their view concerning the role of HPS in this respect? (ii) To what extent does a teaching strategy built in the light of HPS and introducing some elements of HPS allow students to overcome the learning difficulties and reach a deeper understanding of the concept of energy? In the following sections, we present the way we built our HPS-based teaching strategy, the method for assessing it, before discussing our main results.

Building an HPS-Based Teaching Strategy

So as to build a relevant HPS-based teaching strategy for energy, we first carried out (1) a review of the literature in science education so as to identify students' learning difficulties which have to be taken into account; (2) an analysis of the French national programmes and of the French science textbooks in order to adapt the teaching strategy to the context of the country in which the study is undertaken; and (3) a historical and epistemological study concerning energy with the aim to get a new insight on the meaning of the concept and in particular to understand why the concept has entered the field of physics in the middle of the nineteenth century. Steps 1 and 2 are presented in Bächtold et al. (2014) and step 3 in Bächtold and Guedj (2014). We summarize here the main outcomes of the historical and epistemological study (step 3), which was based on secondary (and some primary) historical and philosophical sources concerning energy (e.g. Meyerson 1908; Kuhn 1959; Poincaré 1968 [1902]; Elkana 1974; Lindsay 1975; Harman 1982; Bunge 2000; Smith 2003). It is well-known that energy as we understand it today was introduced in physics when the principle of energy conservation was established; for this reason, many physicists consider that conservation is a fundamental property of energy (Balibar 2010). Nevertheless, there is another important part of the story which is less known. Let us present it in few words. Before the very notion of energy was introduced, in the first part of the nineteenth century, physicists performed a whole set of new experiments which could be viewed as "conversion" processes between different kinds of phenomena, that is, phenomena which were usually handled in different branches of physics (e.g. Faraday's electric motor experiment in 1821 which links electricity and movement or Joule's paddle wheel experiment in 1845 and 1847 which links movement and heat). In this context,

energy was introduced as a unifying conceptual tool which allowed an explanation of how these phenomena were linked together, that is, how heterogeneous quantities (e.g. living force and heat) could be converted into one another: Thomson and Rankine proposed viewing these quantities as instances of the same quantity, namely, energy, and describing each conversion process in terms of energy transformation – the amount of energy being constant during the process. Moreover, to conceive the convertible quantities (e.g. living force and heat) as instances of the same quantity, they defined energy as the "capacity of a system to perform changes" (this definition being known as "Rankine's definition"): these quantities are equivalent with respect to the capacity of the systems under consideration to produce the same changes (e.g. the increase of temperature in the case of Joule's experiment). This historical and epistemological study brings to light two important points: the unifying function of energy and the role of Rankine's definition.

The fourth step of the research consisted in building, implementing and assessing a new teaching strategy for energy that relies on HPS and in particular on the points stressed above. We chose to focus on high school, at grade 11, a school year in France during which energy has to be studied in several teaching sequences of physics and chemistry. Taking into account the contents clarified in the previous steps of our research (steps 1–3), we came to develop a teaching strategy consisting of (a) a teaching sequence beginning with the study of a historical text of Joule (Joule 1847b) and centred on Joule's paddle wheel experiment (Joule 1847a) and Rankine's definition (Rankine 1855); (b) a prestructured conceptual map of energy (called "ID card") to be filled in by students during the school year, which is intended in particular to help them to differentiate various concepts associated to energy that are often confused (i.e. sources, forms, transformations and transfers of energy); and (c) the introduction of the conservation principle the first time the quantity energy is dealt with during the school year, followed by multiple applications of this principle. We would like to emphasize that the choice of introducing Joule's experiment was motivated by the fact this experiment can illustrate in a simple manner the notion of transformation between two energy forms (i.e. kinetic energy and thermal energy) which, moreover, are usually studied in two separate branches of physics (i.e. mechanics and thermodynamics). The relevance of introducing this experiment in the frame of energy teaching has also been stressed recently by Lehavi et al. (2016).

Following the "design experiment" method (Cobb et al. 2003, Sandoval 2013), we then undertook collaborative and iterative work involving teachers: collaborative so as to build teaching sequences meaningful for teachers, not too far from their usual practices, and compatible with the constraints of the school environment, iterative, that is, with two loops of implementation and assessment, in order to improve the teaching sequences.

In accordance with the national programme for grade 11, a total of eight teaching sequences involving the concept of energy (either as a central or a secondary item) were designed and implemented in each class. Let us describe in more details the HPS-based teaching sequence centred on Joule's paddle wheel experiment and Rankine's definition. This sequence consisted of three activities and had a total duration of around 4½ h. In the first activity (around 1½ h), teachers first provide a

document describing the scientific and technical context at the time of Joule. Students are then asked to study a historical text of Joule published in 1847 (an extract from "On matter, living force, and heat"). The first part of the text deals with the notion of living force and is used as a support for a discussion with students about the difference between force and energy. The second part explains the problem faced by Joule concerning the disappearance of living force and sets out the solution he proposed (i.e. interpretation in terms of conversion of living force into heat; experiences performed to support this interpretation). Teachers then describe Joule's paddle wheel experiment in terms of energy transformation (i.e. kinetic energy into thermal energy). Finally, they formulate and discuss Rankine's definition of energy (i.e. they discuss the terms "capacity" and "changes") paying attention to the unifying role of energy. In the second activity (around 2 h), the teachers ask students (in small groups of 3–5 students) to conceive a similar experiment with current materials available at home or in the teacher's laboratory, to perform it and to present and discuss their outcomes. In the last activity (around 1 h), students complete an exercise with mathematical calculations concerning Joule's experiment which compels the use of the notions of energy dissipation and energy conservation.

Method

The teaching sequence has been implemented in grade 11 classrooms for 2 consecutive years, with three experienced high school teachers (T1, T2 and T3) during the first loop of implementation and assessment (year 1) and two teachers (T1 and T2) during the second loop (year 2). To address our first research question (i), related to teachers' view on HPS-based teaching of energy, we analyse the two implementations. As regards the effectiveness of the teaching strategy (research question (ii)), we restricted our analysis to the results of the 2nd implementation, those concerning the first experimentation being presented in Bächtold et al. (2016). During the second year, T1 implemented the teaching strategy in 1 class (27 students) and T2 in 2 classes (35 students and 33 students). Both teachers described the students of the second year as having overall a "rather low level" in physics compared to the students in the classes they had taught in the past.

To address the two research questions, we collected the following data. The HPS-based sequence was videotaped, and evidence of students' activities was collected. Note that the detailed analyses of the videos are presented elsewhere (Bächtold & Munier, submitted). As regards teachers, three working meetings were audio-recorded in the context of which we performed semi-structured interviews, on the basis of selected video extracts of classroom activities. At the end of the school year, in the context of a final meeting with the teachers, we also gathered complementary information concerning the other teaching sequences where the quantity energy was involved, concerning the way the ID card of energy was used and the number of applications of the conservation principle.

As regards students, they were asked, during the teaching sequence, to perform an experiment similar to the one carried out by Joule ("raise as much as possible the temperature of a quantity of water in 10 minutes, starting with kinetic energy") and to make a short video of this experiment presenting the protocol and discussing the outcomes. These videos (15 video recordings of students' experiments, each 1 of an average duration of 2′30″) were analysed, focusing on students' use of the notion of energy transformation. We also proposed written pre- and post-tests to assess the evolution of pupils' knowledge about energy.

The pretest (N=95) consisted of five open-ended questions. Six questions were added in the post-test (N=87), one open-ended question and five multiple-choice questions adapted from the questionnaire of Neumann et al. (2013). This questionnaire was distributed by these authors to a large number of pupils, which allows us to have a reference level when we analyse the answers and assess the level of the students involved in our experiment. These six further questions dealt with quantities and notions which were introduced during the school year, so we considered it meaningless to include them in the pretest.

In question 1, students were asked to describe in terms of energy the following situation: a person turns the crank of a flashlight, which emits some light. We wanted to determine whether pupils were able to describe this situation in terms of forms and transformations of energy. In question 2, to determine whether students confuse energy with other quantities closely related to energy (e.g. force and power), students were asked to provide all of the energy units they know. Question 3 addressed the unifying role of energy. We remind students that the curriculum for their level emphasizes the concept of energy, and we ask them whether they have an idea about the reasons for this emphasis. We want to determine whether students spontaneously mention the unifying role of energy. In questions 4 and 5, students were asked to explain what energy is for them and what the properties of energy are. These two questions were analysed together in order to determine if students are able to provide Rankine's definition and if they spontaneously mention energy transformation and the conservation principle. The remaining questions were included only in the post-test. Question 6 concerned the gap between how energy is addressed in physics and in everyday life. We remind students that in everyday life, we often speak of "production" or "consumption" of energy before asking them whether, from the point of view of physics, energy could be produced or consumed and to justify their answer. We want to determine whether students are capable of translating these expressions into scientific terms (e.g. in terms of "transformation" or "dissipation") and what is the status they grant to energy conservation. Questions 7–11 were multiple-choice questions addressing concrete physical situations. In Question 7, the picture of a marble held at the top of a bowl is presented, and students must choose between several statements claiming that the ball has or does not have various forms of energy. We wanted to determine whether students confuse the different forms of energy or whether they associate energy with motion or with a human action. In questions 8 and 9, the picture of a ball dropped and making round trips in a bowl is presented. Question 8 aims at determining whether students are able to correctly describe the situation in terms of transformation of a form of energy into

another, whereas question 9 examines whether they can explain the slowing down of the ball in terms of energy dissipation without dismissing the conservation principle. Questions 10 and 11 concern the working principle of a wind turbine that produces electricity. We aim at knowing whether students are able to explain its functioning in terms of energy transfer and of energy transformation and are capable of analysing the situation in terms of dissipation and conservation of energy. The complete questionnaire and the detailed coding grid are presented in a paper currently under review (Bächtold and Munier 2018).

Results

With regard to our first research question, the classroom video recordings and the collective semi-structured interviews with teachers yielded the following outcomes. The interviews brought out that the three teachers were enthusiastic concerning the activity based on Joule's experiment. Teachers stressed that students were very motivated to conceive their own experiment, to perform it and to film it. They then considered the activity based on Joule's experiment as a very good tool for raising students' interest for energy. They also consider that performing their own experiment allows students to make the idea of energy transformation more concrete for them, helping them to understand the notion of energy transformation.

The three teachers were also enthusiastic with respect to the introduction of history of science in their classrooms via the study of the historical text. They stressed that such an activity can contribute to the cultural literacy of their students. At the end of year 1, the teachers viewed the historical text as "too long" and some parts of it as too difficult for students to understand. They viewed the expression "living force", used by Joule, as confusing for students. This feedback led us to adapt the activity for year 2 by removing parts of this text, reformulating the questions aimed at guiding the students and proposing a slide to be projected at the end of the activity to summarize the difference between force and energy. Recall that our assumption is that the discussion of the expression "living force" is a good opportunity to clarify the distinction between force and energy. At the end of year 2, the two remaining teachers no longer considered the text too long or difficult.

Concerning Rankine's definition, at the end of year 1, teachers did not appear to understand well its role in the strategy for teaching energy. Thus, in their classrooms, they only mentioned it in passing (as we could see in the video recordings). In year 2, after longer discussions about the role of this definition in the understanding of energy, we decided with the teachers to devote more time to the discussion of this definition in the classrooms. In the interview at the end of year 2, both T1 and T2 agreed that the introduction of Rankine's definition, by discussing the terms "changes" and "capacity", was more meaningful.

The three teachers were very positive regarding the training their received through this collaborative work. They initially ignored how energy was introduced in the history of physics and had no idea of the unifying role fulfilled by this quantity.

Our meetings helped them to understand this point. At the end of the second year, the two remaining teachers emphasized that the ID card of energy was very useful in order to integrate this unifying role in their classrooms. This tool was described as a "guideline" so as to establish links between the various lessons during the year where energy is at play. The word "guideline" was used both by T1 and T2. In the view of T2, this tool could also be very helpful for his students during their next year (grade 12), as it provides an overview concerning all the aspects of energy that have been studied during this year. According to T1, the ID card "has a role of binder […], it gives a meaning to energy throughout the school year, [this meaning being] hidden in some words, in some chapters;" otherwise, the chapters appear as merely "juxtaposed". Note that the teachers proposed adding a timeline in the ID card and using this as a means of constructing historical landmarks concerning the contribution of famous physicists (e.g. Joule, Rankine, Planck, Einstein, etc.) to the history of energy in the various domains of physics.

Finally, taking into consideration the low results concerning the application of the conservation principle year 1, we chose to introduce it earlier year 2. Teachers were in favour of this strategy, but in their view, the mastery of this principle by their students seemed to be only one pedagogical goal among others, and not the overarching goal of energy teaching.

Concerning the efficiency of the teaching strategy (research question ii), the answers to the pre- and post-tests are summarized in Table 1.

Let us provide details on some of the outcomes provided in Table 1. In question 1, the number of students providing a description in terms of energy transformation, at least of one element of the chain, increases significantly.

Concerning question 2, we note that the percentage of students able to name one or more correct units of energy without also stating an incorrect unit increases from 7% to 39%. However, the number of students providing an erroneous unit remains important. In particular, the number of students providing a unit of force remains similar between the pretest and the post-test (difference not statistically significant), which suggests that confusion persists between energy and force. Concerning question 3, the percentage of students able to mention spontaneously the unifying role of energy increases, but the difference is not statistically significant. When they are asked to provide a definition of energy (Q4), Rankine's definition or a distorted but acceptable version of this definition (e.g. with the idea of capacity) is more frequent after teaching than before, by an amount that is statistically significant.

Answers to question 6 show that a large percentage of students after teaching is able to interpret correctly the expressions "production" and "consumption" of energy, namely, in terms of energy transformations.

According to answers to questions 7–9, most students, in the specific situation of a marble in a bowl, have acquired well the notions of kinetic and potential forms of energy and are able to describe this situation accurately in terms of energy transformation. In this case, the difference from students assessed by Neumann et al. (2013) is statistically very significant. Nevertheless, the outcomes concerning the notion of energy transformation are comparable with the outcomes of Neumann et al. in the case of another physical situation (i.e. wind turbine generating electricity (Q10 and Q11)).

Table 1 Students' answers to the pre- and post-tests (year 2)

	Physical situation	Kind of question	Skills and confusions assessed	Answers to the pretest	Answers to the post-test	Outcomes from Neumann et al. (2013) (details given in private communication)
Q1	A crank flashlight	Open	Notion of energy transformation	Description with a clear idea of transformation		
				26%	54%	
				Significant evolution (χ^2=14.58)		
Q2	Not specified	Open	Measurement units of energy	Correct(s) measurement units without erroneous unit		
				7%	39%	
				Significant evolution (χ^2=26.17)		
				Confusion with force		
				11%	7%	
				Non-significant evolution (χ^2=0.75)		
Q3	Not specified	Open	Unifying role of energy	16%	28%	
				Non-significant evolution (χ^2=3.75)		
Q4 and Q5	Not specified	Open	Definition of energy	Rankine's definition or distorted but acceptable versions of this definition (e.g. with the idea of capacity)		
				5%	40%	
				Significant evolution (χ^2=30,85)		
			Notion of energy transformation	Idea of transformation		
				23%	48%	
				Significant evolution (χ^2=12.57)		
			Conservation principle	Conservation principle		
				5%	53%	
				Significant evolution (χ^2=51.04)		
Q6	Not specified	Open	Energy "production/consumption" interpreted in terms of energy transformations		61%	
Q7	A marble held at the top of a bowl	Closed	Notion of kinetic and potential forms of energy		86%	45%

Table 1 (continued)

	Physical situation	Kind of question	Skills and confusions assessed	Answers to the pretest	Answers to the post-test	Outcomes from Neumann et al. (2013) (details given in private communication)
Q8	A marble rolling in a bowl	Closed	Notion of energy transformation	88%	48%	
			Confusion between energy and force	6%	/	
Q9		Closed	Conservation principle with the relevant system	37%	20%	
			Confusion between energy and mechanical energy conservation	16%	/	
Q10	A wind turbine generating electricity	Closed	Identification of various forms of energy and notion of energy transformation	42%	49%	
			Confusion between energy and force	35%	/	
Q11		Closed	Conservation principle and notion of dissipation	51%	31%	
			Confusion between energy and force	38%	/	

Answers to questions 9 and 11 show that the percentage of students mastering the principle of energy conservation is higher in our study than in the one of Neumann et al. (2013), this difference being statistically significant. This is the case in a situation in which they might confuse it with the conservation of mechanical energy and in which they must identify the relevant system (Q9), as well as in a situation in which dissipation must be considered (Q11). Another outcome that must be emphasized is that the force-energy confusion remains latent for many students. For example, although few of them appear to confuse these two quantities in the situation of a marble in a bowl (6%), more than one-third experience this confusion in the situation of the wind turbine.

Let us turn finally our attention to students' videos. Our analysis shows that 5 groups out of 15 spontaneously described the experiment in terms of energy transformation, 4 groups spoke about kinetic energy and heat without using explicitly the idea of transformation and 6 did not even mention the notion of energy. More details concerning this analysis are given in Bächtold and Munier (2018).

Discussion and Conclusions

Let us recall our first research question: Does a collaborative work aimed at introducing HPS in the teaching of energy help high school physics teachers to understand the issues of energy teaching and change their view concerning the role of

HPS in this respect? Our case study suggests that teachers can be very receptive to the contribution of HPS. The three teachers participating in this study particularly acknowledged the insight that HPS gave them into the unifying role of energy in physics. Understanding this unifying role was very helpful for them to give meaning to the high school programme of physics and chemistry, which involves numerous chapters dealing with energy without apparent relationships. This new insight for teachers into their understanding of energy has been manifest in the interest they showed for the ID card of energy.

Overall, the teachers in this case study were very involved in the collaborative work, not only for the implementation of the teaching sequence but also for its design by making several proposals (e.g. they proposed to add a timeline in the ID card that students provide a video recording of their experiment and changes concerning the selected historical texts). This commitment can be viewed as evidence they considered the introduction of HPS meaningful in their teaching.

More specifically, although the teachers did not assign a major role to Rankine's definition, they were very positive concerning the study of Joule's paddle wheel experiment and its replication with their students. It has been identified not only as a good means for raising their interest concerning energy but also, and more fundamentally, as a meaningful illustration of the idea of energy transformation. As further evidence, let us note that one of the two teachers who took part in our study the second year is still implementing the HPS-based sequence (with Joule's experiment) 3 years later and outside the frame of our research (the other one is now teaching students at other grades).

These outcomes are in line with previous studies which emphasize the interest generated by providing science teachers with training about HPS. As Matthews (1994) argues: "many examples have been given where HPS can contribute to better, more coherent, stimulating and critical teaching of specific curriculum topics" (pp. 200–201). Irrespective of the introduction of HPS in classrooms, training teachers about HPS can give them an insight into the meaning and the role of experiments and concepts they teach.

Concerning our second research question about the effectiveness of the teaching strategy, data analysis shows that the implemented teaching strategy allowed a large proportion of students to identify correctly and distinguish the energy forms and to apply accurately the notion of energy transformation in various situations. However, this level of mastery seems dependent on the forms of energy involved: students seem to master the potential-kinetic energy transformation, two forms of energy with which they have been familiar for several years and which can be more easily associated with a system. They have more difficulties with light and electrical energy, "forms" which are not consensually defined in the scientific community and which are more difficult to associate to a system.

The comparison with the results of Neumann and colleagues shows that the teaching strategy seems more effective than a classical one for helping students to apply correctly the conservation principle without confusing it with the conservation of mechanical energy, taking into account dissipation and identifying the relevant system. It seems to confirm the relevance of introducing this principle from the

first time energy is studied in the school year and applying it several times during the year (and not only after having studied mechanical energy).

Results are more mixed concerning the energy-force confusion; depending on the context, up to a third of students made this confusion. The study of a historical text designed to discuss this confusion can be an interesting tool but can also have a possible counterproductive effect with less skilled students.

A limitation to the assessment of the teaching strategy is the relative gap between the sequence as it was envisaged by the researchers and the sequence actually implemented, due to various uncontrollable constraints of the school environment. By carrying on the iterative process of implementation and adjustment of the sequence, we may reduce this gap, better determine the relevance of the strategy and imagine possible improvements.

Even if we do not claim that HPS should be introduced systematically in science teaching, this research points out its usefulness for building new science teaching strategies and illustrates how HPS may be introduced in classrooms. Indeed, the historical and epistemological study carried out as a preliminary step of this research provided us with a new insight into the meaning of energy: in particular, it brought to light both the unifying function of the concept and the important role of Rankine's definition. These two points have been decisive in the development of our teaching strategy. Concerning the introduction of some elements of HPS directly into the classroom, Joule's paddle wheel experiment appears to be a simple and easily understandable experiment and, at the same time, a powerful illustration of the notion of energy transformation. Thereby our research shows that historical experiments can help students to understand better the scientific contents and possibly play the role of a paradigmatic example. In this regard, HPS does not merely supply a cultural extra to the study of the scientific knowledge; it appears as a reservoir of potentially fruitful tools for teaching and learning this knowledge.

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An Explorative Laboratory Study: Changing Representations of Functional Dependencies in Physics Class of Lower Secondary School

Marie-Annette Geyer and **Gesche Pospiech**

Introduction

In physics functional dependencies and their representations enable us to describe, explain and investigate physical phenomena or relations. Tables, graphs, algebraic expressions or verbal descriptions representing physical relations matter as well in different teaching and learning situations, e.g. analysing experimental data or solving tasks and problems.

According to Airey and Linder (2009), students can only understand a physical concept in an appropriate way if they know how to make use of different representations. Only when they know how to extract information from these representations, construct them, and change between them, a holistic experience of the physical relation is possible. Ainsworth (2008) states as well that multiple representations can support learning and can lead to a deeper understanding in science. Yet, to take advantage of multiple representations, learners have to know how to relate them to each other and to the content they are representing. Changing between different representations is crucial for learning and understanding physics. However, there is also evidence that it is a highly complicated task for learners, especially for novices (cf. Ainsworth 2008).

So far research in physics education has investigated how students succeed in changing between different representations in the context of physics in comparison to the context in mathematics (cf. Ceuppens et al. 2018). However, researchers have not focused on how students proceed during this transformation of representations in physics. This process will be explored in the presented project.

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An investigation of the students' activities, rationales and difficulties during a transformation of representations in physics will lead to a better understanding of this process and could finally result in the design of supporting teaching and learning situations in that respect.

Change of Representations in Physics

The process of changing between or rather transforming two different representations of functional dependencies in physics can be described by the model in Fig. 1 (cf. Geyer and Pospiech 2015; Geyer and Kuske-Janßen 2019).

When students transform a source representation, e.g. a table, into a target representation, e.g. a graph, they can follow different kinds of activities. These activities (represented by circles and ellipses in Fig. 1) can be grouped (A, B, C) and mapped to either a technical or a structural translation (cf. Pietrocola 2008; Karam and Pietrocola 2010). However, a translation between two different representations does not mean that the representations themselves are translated into each other. It rather means that their elements and structures and the contents that are represented within have to be transferred in an appropriate way.

The groups of activities A, B and C were derived from the translation-verification model by Adu-Gyamfi et al. (2012) which was initially developed for linear relationships in mathematics. The definition of its elements was adjusted to fit with general functional dependencies in physics (see Table 1).

When students apply acitvities of the groups A, B or C, they could either follow (i) a technical or (ii) a structural translation. Referring to the technical and structural
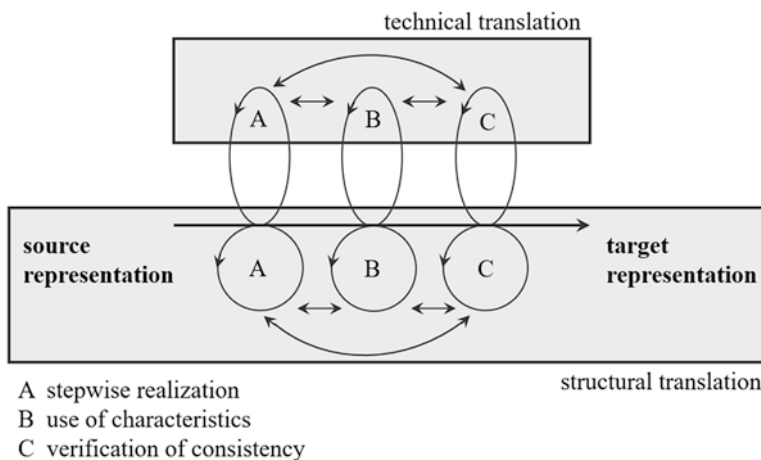

Fig. 1 Model of changing representations of functional dependencies in physics lesson. (cf. Geyer and Pospiech 2015; Geyer and Kuske-Janßen 2019)

Table 1 Brief descriptions of activities A, B and C

Activities A: stepwise realization	When students follow step-by-step actions during a change of representations, similar to applying an algorithm, these actions are categorized here. For instance, transforming a table into a graph, students insert the given values as points into the frame of the graph and draw a line between them out of habit. The origin of this group of activities is the construct *implementation verification* found by Adu-Gyamfi et al. (2012).
Activities B: use of characteristics	These activities focus on using key characteristics for the translation. That can have different forms: On the one hand, students could use explicitly given characteristics, e.g. the values of the intersections of a curve with the coordinate axes in a graph. On the other hand, they could use implicitly given characteristics, e.g. the kind of dependency between the related quantities in the source representation. Furthermore, it is possible that students assume characteristics that are not correct; for instance, they follow translation processes assuming a proportional relationship between two quantities, yet the physical laws are different from this. This group of activities is based on the *attribute verification* found by Adu-Gyamfi et al. (2012).
Activities C: verification of consistency	Activities that concern a verification of the consistency of the source and the target representation are categorized in this group. It means that students check their translation process in some way after they have created elements of the target representation. For instance, they examine if pairs of values that can be calculated by a given formula are part of the graph that they have constructed as a target representation. This group of activities was derived from the construct *equivalence verification* found by Adu-Gyamfi et al. (2012).

role of mathematics and physics (cf. Pietrocola 2008; Karam and Pietrocola 2010), these two kinds of translations describe if and how the students connect both of these disciplines in their reasoning. This distinction enables us to investigate to which extent students think about the physical meaning of the mathematical representations and relations and if they achieve new insights through it.

(i) Technical Translation

When students do not make any connection to physics and follow routines and habits and recall memorized rules, conventions or superficial characteristics, we name this a technical translation. Students stay within a formal reasoning which is, for instance, based on surface features of the mathematical relation.

(ii) Structural Translation

Within a structural translation, a connection between mathematics and physics can be detected. However, students can have a different focus on one of the disciplines or connect them in a balanced way, as, for instance, illustrated in the study of Schoster (1998):

- *focus on maths*: The students reason with the help of mathematics and finally connect or transfer their thoughts to physics.
- *balanced*: The students connect mathematics and physics in their reasoning in a balanced way. Both disciplines are strongly intertwined.

- *focus on physics*: The students predominantly reason with the help of physics and only connect their thoughts to mathematics from time to time.

When students transform representations, they can apply activities of different groups in a different order. Furthermore, it is expected that not all of the six elements of the model in Fig. 1 will occur within one process of changing between two representations.

Research Goals

In physics, changing between different representations is an important competency in order to grasp a physical relation in a holistic way. Thus, students should start to develop the corresponding skills from the start of learning physics. This project investigates the students' perspectives concerning this topic in lower secondary school. As a first step, students' existing knowledge, the way of thinking and reasoning and difficulties should be explored. Thus, this project sets out to investigate the following research questions:

- How do students work on physical-mathematical tasks that include different transformations of representations of functional dependencies?
- Which activities do they follow during the transformation of representations?
- What kind of rationales do they give for their different decisions while transforming representations?

Method

An explorative approach was chosen since it has not yet been studied how students of lower secondary school transform representations of functional dependencies in physics. The investigation of students' transforming representations was conducted by means of three to four physical-mathematical tasks. One of these tasks is presented in Fig. 2 and relates to a change from a table to a graph.

The tasks were designed in a way that they offer structural translation elements next to technical ones. Furthermore, it is not possible that students could solve these tasks only with routines. For instance, the task *Cooling process* (see Fig. 2) contains the following particularities:

- The process of cooling follows an exponential relationship that the students of the target group usually do not know. This triggers them to think more deeply about the task compared with a task with a known relationship.
- The time intervals are chosen irregularly which would not be common in a real experiment. This allows to see how profoundly they look at the data in exploring the relationship.

Cooling process

A liquid is heated to 300 ˚C and then taken away from the heating source. During the process of cooling the temperature of the material is measured for 30 minutes.

Draw an appropriate graph which shows the progression of the temperature of the material during the first 30 minutes of the cooling process. Describe and reason how you proceed.

The following data is known (The last value is no longer readable.).

0th minute	3rd minute	8th minute	12th minute	18th minute	26th minute	30th minute
300 °C	260 °C	207 °C	175 °C	136 °C	99 °C	

Fig. 2 Example of a physical-mathematical task which the students worked on

- The missing data in the table invites the students to think about the process as a whole and asks them to make predictions.
- The temperature of the environment is not given to investigate if the students consider this factor influencing the process. Furthermore, without mentioning it, a linear regression would still be technically possible.
- Choosing a material that is liquid at 300 °C and does not change its state cooling down to approximately 80 °C provides another opportunity to think about physics and not only to consider a well-known situation.

To examine the students' perspectives and lines of thought, a discussion of two students was conducted in which the test persons explained their ideas to each other while writing on an interactive whiteboard. Afterwards an interview helped to clarify inconsistencies and difficulties that had been observed.

The recorded discussions and writings of the students were completely transcribed and are analysed according to the method of qualitative content analysis by Kuckartz (2016). Thereby, students' steps are structured by means of deductive and inductive categories and allocated to the groups of activities in the model of changing representations (see Fig. 1). This will be a step towards a first validation of the model.

To increase the quality of the analysis, physics education experts and trained intercoder and interrater were included in the process: The definitions of the categories were discussed within the own research group and with researchers of other groups. An intercoder was trained in the categories derived from the model of changing representations (see Fig. 1) and coded 30% of the material. After adapting the coding manual, the intercoder agreement was 63%; Cohen's kappa was 0.6 and was calculated after Brennan and Prediger (1981). Because the categories are not thematic but evaluative, this is a good result (cf. Kuckartz 2016) and shows that manually describing all the categories works well. The rating of correct and false solutions of the students was approved with the help of a trained interrater. An agreement could be found after the discussion.

Sample

The 17 pairs of students that participated in the study in 2015 came from 8 different schools (Gymnasium) in Saxony, Germany. They were aged about 14 years. The students attended with a team partner who was their friend and usually attended the same class at the same school. In all pairs both partners had the same sex. Ten of the pairs were female, and seven pairs were male.

The grades on the students' last school report in physics and mathematics (see Fig. 3) reveal that students with different background knowledge and skills participated in the study. Usually the team partners had similar grades.

The average grades of the observed students were 2.4 and 2.5 in physics and mathematics, respectively. Although it seems that students with good grades are predominant in the sample, a comparison of 309 Saxon students of this age shows no differences (average grades: 2.3 in physics and 2.4 in mathematics).

Results: Transforming a Table into a Graph

In this article the results concerning the task *Cooling process* (see Fig. 2) are presented. Out of 17 pairs of students, 6 pairs submitted a correct solution (see, for example, Fig. 4). The results of 5 pairs were not complete, and the results of 6 pairs were evaluated as false (interrater consistency before discussion 13/17, after discussion 17/17).
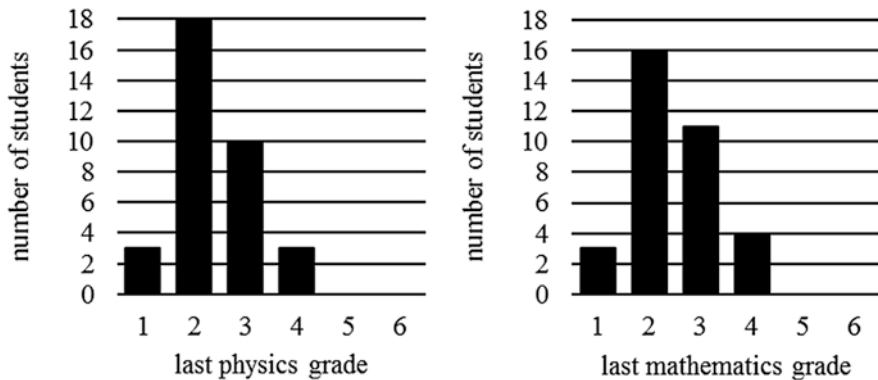
Fig. 3 Physics and mathematics grades on the last school report of the 34 students that participated in the study (1 excellent, 4 sufficient, 5/6 failure). The average grades are 2.4 (physics) and 2.5 (mathematics)

0. Minute	3. Minute	8. Minute	12. Minute	18. Minute	26. Minute	30. Minute
300 °C	260 °C	207 °C	175 °C	136 °C	99 °C	
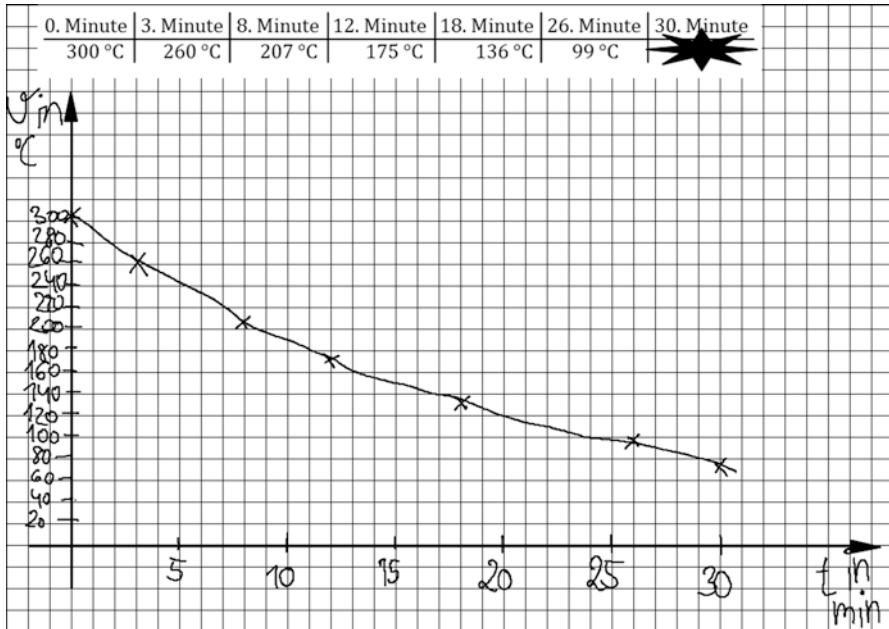
Fig. 4 Result of the task *Cooling process* (see Fig. 2) by Julia and Rosie assessed as correct

During the change from a table to a graph, most of the students went through the following main steps:

- Choosing proper quadrant(s) and scaling the axes (different quadrants with a grid were provided at the interactive whiteboard and opened automatically when chosen)
- Relating the variables time and temperature to the axes and labelling them
- Inserting single points
- Sketching a curve
- Extrapolating temperature for the 30th minute

Students' Activities

The analysis of the data indicates that all 17 pairs applied activities that are mapped to groups *A stepwise realization* and *B use of characteristics* of the model of changing representations. Eleven pairs of students even showed retrospective elements (*C verification of consistency*).

During analysis the single steps that the students followed to represent the given data of a table within a graph are separated from each other (see Fig. 5). It can be noticed that not all three groups of activities (A, B, C) occur during every step. For
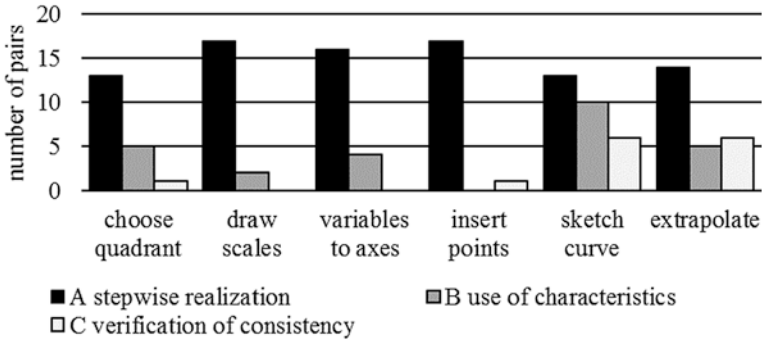
Fig. 5 Occurrence of the activities derived from the model of changing representations (see Fig. 1) in the task *Cooling process* (N = 17 pairs). The students transformed a table into a graph. Each pair of students performed several kinds of activities
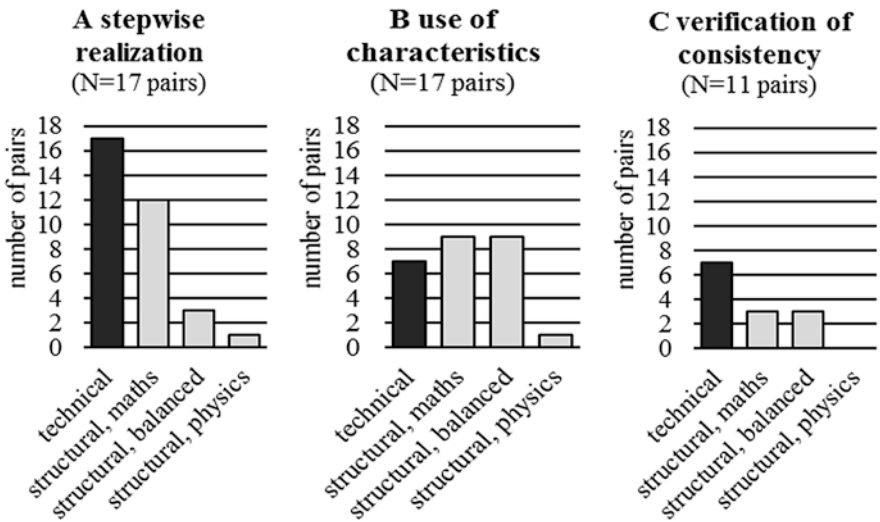
Fig. 6 Appearance of the activities derived from the model of changing representations (see Fig. 1) in the task *Cooling process* (N = 17 pairs). Each pair of students performed several kinds of activities

instance, the observed students did not apply activities of group *B use of characteristics* when they inserted points. Activities of group *C verification of consistency* especially occurred when they sketched a curve or extrapolated the temperature for the 30th minute.

All three groups of activities (A, B, C) occurred both in a technical and structural way (see Fig. 6) which will be described in more detail in the following sections.

Activities A: Stepwise Realization

As expected, group A appeared predominantly within a technical translation. It is in the nature of step-by-step actions of an algorithmic character that students can apply these actions without thinking about a lot of structural elements behind it. It can lead to an efficient solving of a task. This, for instance, applies to scaling axes and inserting points. When activities of this group occurred in a structural way (12 pairs), there was mainly a focus on mathematics. For instance, some students talked about the shape of the curve to extrapolate the temperature to the last minute:

Rieke: *At least it goes down.*
Lena: *Thus, it must be somewhere in this lower part here.*
Rieke: *And actually the descent is relatively gently. Theoretically it would continue like this, I would guess...*

Activities B: Use of Characteristics

Although all 17 pairs showed activities that are classified in B, four of them related to this group of activities only in the interview afterwards. There they gave (additional) reasons for their solutions. From Fig. 6 it can be seen that activities B occurred mainly as part of a structural translation (13 pairs) either with a focus on mathematics or in a balanced way. The characteristics that the students used were predominantly connected to the kind of dependency that they assumed between temperature and time. They talked about (not) linear relations and proportional relations when they sketched the curve or tried to figure out the temperature for the 30th minute. Furthermore, this group of activities was coded in the data as well, when the students thought about the shape of the curve while they still constructed the frame of the graph, i.e. before they inserted the points.
Ulrike: I would take…this (all four quadrants, authors' note). Because for the 30th minute you don't know if it goes…into zero.
    In the interview afterwards:
Ulrike: Well, firstly when you haven't anticipated yet what…curve comes out. And here you have free possibilities.

Activities C: Verification of Consistency

Activities that concern group C occurred mainly when the students had already finished the frame of the graph and were about to insert values and relations into the graph. They were performed almost evenly technically (7 pairs) or structurally (6 pairs). There were no activities of group C detected that are part of a structural translation with a focus on physics. As the students were checking single steps within the

interpretation and construction of mathematical representations, it can be assumed that this happens either in a balanced way or with a focus on mathematics if it is performed structurally.

Mostly students first started with activities coded as *A stepwise realization, technical* and then continued with activities of *C verification of consistency*. For instance, when they attempted to sketch a curve, they started with a straight line out of habit. Then they noticed that it does not fit and thought about it again.

Students' Rationales

The data reveals that the students had quite different rationales for their choices and decisions while they were working on the task. These rationales were the indicators to decide if they followed a technical or a structural translation process (according to the definitions of both of these types of translations given above). For four of the main steps referred to above, an overview of students' rationales with some examples will be presented in the further sections.

Choosing Proper Quadrant(s)

As a first step of the task, the students had to choose which part of the coordinate system they want to use to present the data in a graph. Fifteen pairs chose the first quadrant, and two pairs chose all four quadrants. Most of the students justified this step with arguments coded as a technical translation (see Fig. 7). For instance, they discussed that the values in the given table are positive, i.e. that they do not need negative values. One pair added that they usually use this part of the coordinate system in physics lessons. Some pairs stated that they only need two axes because they only have two variables (time and temperature).

There were structural rationales given as well: Students either focused on mathematics and talked about the quantities, and for these, only positive values were given. Or they focused on physics and argued that the material does not freeze, and for this reason, there are no negative values or parts of the axes required. Two pairs connected mathematics and physics in a balanced way as the following example illustrates:

Nuri: Well, it cools down. When it continues dropping. […] Well, you don't know how strongly it is dropping. […] Okay. Yes, then we can take this (first quadrant, authors' note)…can't we?

Raja: Yes, if outside, if you take it outside and there are minus 15 degrees, then it could become even colder. So this one (first and fourth quadrant, authors' note).
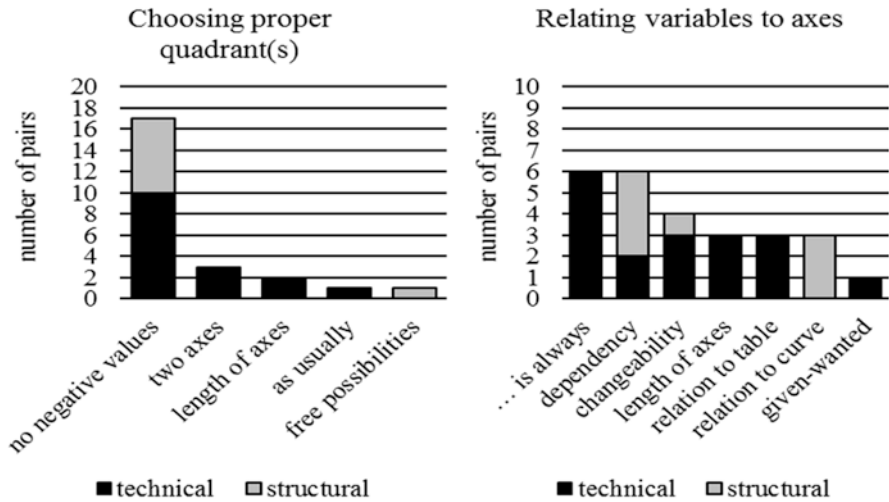
Fig. 7 Cited reasons of the students while choosing a proper part of the coordinate system and relating the variables time and temperature to the axes (N = 17 pairs). Sometimes one pair named several reasons

Nuri: *Yes, but within the first 30 minutes. And if you look at the trend of the temperature, it isn't decreasing so drastically that it gets into the negative range.*

Relating Variables to Axes

To label and scale the axes, the students had to decide how to relate the variables to the axes first. All but one pair decided to have time at the x-axis and temperature at the y-axis. Most of the reasons were again technical (see Fig. 7). They tried to recall memorized rules, such as that the time or the varied variable belongs always to the x-axis. Some took the different length of the given axes into consideration or related to conventions of presenting values in a table as the following example demonstrates:

Interviewer: *Why did you put the time here and the temperature on the y-axis?*
Sandra: *Well, we needed more space for the minutes. […]*
Interviewer: *Could you relate them vice versa as well?*
Ina: *Yeah, well, in the tables you usually have x on top.*

If the rationales had a structural character, it could either be that the students focused on mathematics and, for instance, imagined the shape of the curve already:

Martin: *Well, because the temperature drops we have to begin on top.*

In the interview afterwards:

Interviewer:	*Was there a reason why you put the time on the x-axis and the temperature on the y-axis? Or could you relate them vice versa as well?*
Martin:	*I guess they could be related in the opposite way, but it follows because the um…*
Ron:	*Eh? Could you relate them the opposite way? Not at all. Then it would be like this (points from bottom right to top left). Right?*
Martin:	*Yes, you are right. Because the temperature is decreasing it has to go…downwards. The opposite way it would go upwards to the left into the negative range.*
Ron:	*I guess, then it would be the wrong way…*
Martin:	*[…] The temperature would be increasing although it is actually… decreasing. Because if it goes upwards then it would be decreasing. That kind of doesn't work.*

Or a balanced relation between mathematics and physics could be detected. For instance, the following pair talked about the direction of dependency between time and temperature and the setting of the experiment that lies behind the data:

Interviewer:	*Was there a reason why you related the variables like this and not the opposite way?*
Nuri:	*Well, because we wanted to represent the behaviour of the temperature depending on the time. Well, maybe that it will be mapped to it.*
Interviewer:	*Okay. And if you would relate them the opposite way, what then?*
Nuri:	*Yes, then it would be the same but*
Raja:	*Then you would. Well, but then you would have measured the temperature the whole time. And then you would say, okay, at 100 degrees well, the time, no clue…whatever. Well, 25 minutes, 55, um it exactly has the temperature 100 degrees.*

Sketching a Curve

After inserting the given pairs of values as points into the graph, the students sketched a curve (or at least talked about the trend and were then asked to sketch a curve in the interview afterwards). The final results of the students showed either one straight line (3 pairs), point-to-point straight lines (2 pairs), a freehand line (8 pairs), or no curve (4 pairs).

Here again most of the pairs had technical strategies and rationales (see Fig. 8).

Some students sketched a line or even a straight line out of habit; others tested different kinds of curves. In doing so, some also talked about the monotony of the
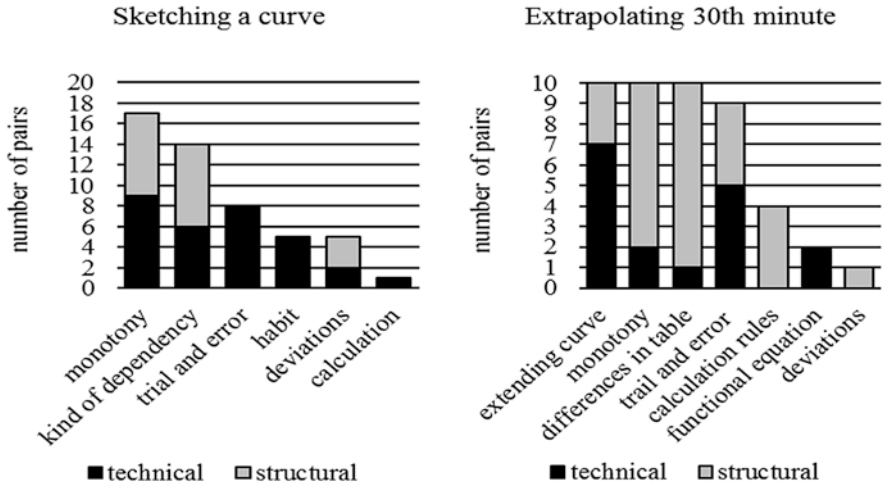
Fig. 8 Cited reasons of the students while sketching a curve and extrapolating the temperature up to the 30th minute (N = 17 pairs). Sometimes one pair named several reasons

curve and tried to associate a kind of dependency (e.g. proportionality) with the relationship.

Relating to these rationales, some pairs connected mathematics and physics in a balanced way. For instance, they discussed as well the uncertainty of measurements to explain why the points are not at a straight line:

Wanda: It is proportional, isn't it?
Iris: Well, now we can draw a line through them […] (Iris draws a straight line from first to last point)
Wanda: And then… Well, you have to go through these points. A little bit more to the bottom maybe. That it is the average… Exactly. Now straight to the bottom…Well, maybe not that sharp. (Iris changes the ending of the straight line) […]
Iris: Well, because of the incorrect measurement it could, because we have drawn these points in a stupid way and because the measurements are a bit bad. Well, it is totally proportional.
Wanda: Well, more or less.

In this step, some pairs just gave a description and not really a rationale, so they could not be mapped to a technical or structural translation. Nevertheless, they talked about the monotony (6 pairs) and the kind of dependency (1 pair) and were added to the graph in Fig. 8 within the rubric "technical".

Extrapolating

As the task was to draw a graph that shows the development of the temperature within the first 30 minutes and there was solely data given up to the 26th minute, the students had to extrapolate. Some students followed a technical reasoning and tried to extend the curve until the 30th minute. Two pairs remembered the strategy to get an equation for the relationship; however, they did not follow this idea.

Only within this step of extrapolation more structural than technical rationales were observed, predominantly with focus on mathematics. Students looked at the temperature difference in the table and/or talked about the monotony of the curve to derive consequences for the continuation of the curve, as the following example demonstrates.

Enrico:	*Well, I would guess at the 30th minute it is about, maybe about 75 or 50 degrees. […] (Enrico and Emil talk more about temperature differences in the table)*
Emil:	*Well, yeah. I would estimate somewhere between 50…*
Enrico:	*Do we say…60 degrees? (marks point (30|60))*
Emil:	*Okay.*
Enrico:	*Although, when you look how the curve goes, 60 would be quite low. Because such a curve that flattens […] if you would connect it.*
Emil:	*Maybe it would be about 70, right?*
Enrico:	*Yes.*
Emil:	*Take it a bit higher. (Enrico changes point)*

Others used calculation rules for indirect proportional or linear relationships to calculate a temperature with the help of the data in the table:

Olessja:	*Well, wait. We can think this mathematically as well. […] Look, here we have 3 minutes and here 30 (looks in the table). Then we have to take it times 10. And because it is the other way around we have to divide it by 10. And I guess this would be 26 degrees, right?...*
Emma:	*Eh? Wait…yeah, you have to. Or you can do it like this. […] You calculate here. […] These are 4 minutes. So we can. Wait. Here is exactly 4 minutes difference. (compares differences between 8th and 12th minute and between 26th and 30th minute)*
Olessja:	*Yes. […]*
Emma:	*Yeah well, these are 32…degrees Celsius difference, if I am right. (calculates temperature difference between 8th and 12th minute) […] Well, then you actually only would have to calculate 99 minus 32… And that are 67. […] (marks point (30|67))*

Discussion and Conclusion

This study gives first insights into how students change between different representations of functional dependencies in the context of physics. The analysed data points out that students show a broad range of activities and ideas while extracting information from a source representation (i.e. a table) and constructing an appropriate target representation (i.e. a graph).

All observed pairs not only followed step-by-step actions and algorithms but also attempted to use characteristics of the relation to get to the target representations. Many of the students (11 of 17 pairs) employed retrospective thoughts and tried to check or improve some of the actions during the transformation of representations. This shows that some students of lower secondary school are already able to apply strategies which would be usually expected from a more experienced learner. However, these retrospective activities were usually applied within single steps during the process and not after the target representation was finished.

Furthermore, the results show that the observed students solely applied activities during a task of change of representations that are sufficient for them to construct the target representation. This means, for instance, that the construction of the frame of a diagram and the insertion of points were dominated by step-by-step actions, whereas the use of characteristics mainly took place when they sketched a curve or extrapolated. Therefore, it is necessary to offer different kinds of tasks in learning situations to experience and train all kinds of activities.

The students employed a great variety of rationales during a change of representations. We observed that the students frequently related solely to their routines, to superficial features of the representations or to recalled rules (technical translation). Nevertheless, many students also discussed more profoundly and attempted to connect mathematical and physical thoughts (structural translation). In this case, still a focus on mathematics was observed more frequently.

Although this article is not about the difficulties of the students, difficulties emerge already from some of the students' quotations that are presented here. Difficulties can occur when students just follow their habits, when students recall rules wrongly, when they assume incorrect characteristics, when they do not check their solving process, when they connect mathematics and physics in a wrong way and so on. Further investigations about the students' difficulties will be part of this project, which also includes transformations of other representations than presented here.

In conclusion changing between representations is a complex process for the students. It requires more than a step-by-step translation. It means rearranging the given information in a meaningful way regarding the context of physics. Some details get lost and new characteristics of the embedded relation are gained or highlighted. Students should see why the use of different representations is important for a holistic understanding of physics. And teachers should help them to become expert in different representations so that they can have access to different aspects of a physical phenomenon or relation. This is only possible when the teachers know

which activities the students could apply and to which kind of rationales they could relate during a change of representations.

Furthermore, this study shows that the theoretical model that has been developed to describe a change of representations of functional dependencies in physics (see Fig. 1) goes well with the gathered data. All activities of the observed students could be coded within one of the groups of activities A, B or C. The same applies to the students' rationales: All statements that could be interpreted could be mapped to either a technical or a structural translation. Hence, the developed model can be evaluated as a first applicable theoretical framework within the qualitative research about transformations of representations of functional dependencies in physics.

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Multiple External Representations (MERs) as a Component of Special Language in Biology

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Introduction

The main purpose of scientific education is the achievement of scientific literacy. Communicative abilities and mastering scientific language are understood as important competencies in the twenty-first century and the key to communication processes (i.e. Chung et al. 2016; Krajcik and Sutherland 2010; Osborne 2002). A plethora of verbal, visual, and symbolic representations is used in scientific education. Verbalizing and visualizing different forms of representations are central abilities for communication processes in school and university. The target of the national educational standards in Germany emphasizes these skills in the competence scope of communication (cf. KMK 2005). Central elements include an active advancement of research, literature, and construction of representations as well as assistance in switching between everyday language and scientific language appropriate to situation and recipient (cf. Stäudel et al. 2008). Studies show especially the language activity by students in class as underrepresented, while the teacher often dominates the discussion (Seidel et al. 2006). This example shows that the condition of special language being only sufficiently acquired or practiced in class. But the meaning-making process needs verbal and visual language (Mortimer and Scott 2000). As a result, it can be presumed that the students can have some problems with technical language when entering university (Lemke 1990; Mortimer and Scott 2000). Therefore, understanding different forms of informational presentation is crucial for the acquisition of knowledge about scientific concepts, principles, and processes.

In the context of a modern education system, combinations of text and figure, so-called multiple external representations (MERs) (Ainsworth 1999), are used frequently. Exercises containing these forms of representation are often not

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51

understood intuitively and trouble students of all ages (ibid.; Kozma and Russell 1997; Schnotz 2002). This process of reading and translating is cognitively demanding. For students it is especially difficult to connect single representations (Seufert 2003). These steps are an important foundation for understanding and communicating scientific structures and are crucial for solving problems in this domain (Hettmannsperger 2015; Kozma and Russell 1997, 2005). Accordingly, it is a duty for schools and universities to include the analysis and integration of more representations in class and teaching as scientific subjects rather draw on MERs instead of single representations. To promote the use of MERs in coherent knowledge structures, learners have to be capable to understand and process each of the representations as a single whole and integrate them into a mental model (Mayer 2014; Schnotz and Bannert 2003). On this account, science education should enable students to interpret, construct, translate, and transform MERs because these aspects form constituent characteristics of developing representational competence (Nitz et al. 2014; Tsui and Treagust 2013).

Current research shows no appropriate competence models concerning the integration of MER in biological science. Previous studies often either concentrate on one type of representation or refer to specific content of a biological topic (cf. Lachmayer 2008; von Kotzebue and Nerdel 2015) or illustrate learning with MER without cognitive processes (Tsui and Treagust 2013). Specifically, competence models, which support the use of a variety of different representations in schools for the integration of MER, are missing. Since not all students profit from MERs to some extent, it remains an open question, under which circumstances a learning success may be recorded and which factors influence the integration.

Theoretical Background

Specialized language is a central element of biological science education. It can be subdivided into horizontal and vertical varieties (Roelcke 2010). The former includes subjects and divisions, the latter the abstraction levels of communication and the linguistic usage types, i.e., scientific language texts. Special language is viewed holistically, and communication defined as verbalized expression and usage of a multitude of different representations (i.e. Ainsworth et al. 2011). Following this concept, scientific language is differentiated by Lemke (1998, p. 3) as a:

> synergistic integration of words, diagrams, pictures, graphs, equations, tables, charts, and other forms of visual and mathematical expression

Biology lessons are characterized by an enormous variety of biology- and science-specific representations. They require context-specific, communicative competencies in learning and performance situations. Biology is characterized by technical texts showing both morphological and syntactical features as well as a variety of forms of representations simultaneously. This includes objects of nature, preparations, drawings and cut sketches, pictures, display and functional models but

also bar, line and flow charts as well as chemical formulas and mathematical equations (Leisen 2015), but also especially characteristic depictions like a karyogram or the picture of a gel electrophoresis. Within the topic of photosynthesis are to be found photos of plants, microscopic shots of stomata and leaf profiles, logical depictions like line graphs showing the dependence between photosynthesis rate and external factors, as well as symbolic representations of the photosynthesis reaction balance (cf. Nitz et al. 2012). Therefore, depictions often relate to other depictions while showing a number of things at once (Jäger 2015). Process-based MERs are also frequent, in which characteristic arrows typically connect single steps (ibid.). Hence, representations are different according to the subtopic in the subject biology. That concerns their frequency as well as their underlying representation itself (Florian et al. 2015). Besides that, MERs are often accompanied by a lot of specific terminology (Enzingmüller et al. 2012). Considering the empirical evidence, only a few studies exist that investigate the extent of dependence between the content and the problem-solving ability (e.g., Lind et al. 2005). Some individual studies report on the content complexity influencing the exercises' difficulty (e.g., Bernholt 2010; Kauertz 2008). As a result, this allows to record information about the necessary domain-specific requirements for solving a problem (Schecker and Parchmann 2006).

Regarding MERs, it is necessary to consider the specific characteristics of texts, pictures, their combination, and the subject-specific features (Ziepprecht 2016). Texts are characterized by missing resemblance to the represented issue and arbitrary structure. The symbol characters are exclusively linked by convention (Schnotz 2002). For students, texts provide the advantages of being rather concrete than abstract and very expressive and that texts are easily readable based on the symbol characters' sequence (Corradi et al. 2014; Kintsch and van Dijk 1978). Whereas, subject-specific texts show impersonal style and carry features like light verb constructions, nominalizations, phrases, and complex attributes (Rincke 2010). Thus, scientific language is often conventionalized and in parts interpretable domain-specific. Pictures are depictive representations composed of iconic symbols and hence exhibit a perceptible resemblance to the represented issue (Schnotz 1994). The degree of abstraction can differ hugely between picture and context: the abstraction continuum extending from realistic over less abstract to abstract with radical reduction of details (Pozzer-Ardenghi and Roth 2010; Schönborn and Anderson 2009; Tsui and Treagust 2013). Logical pictures like diagrams contain a structural analogy of subject area and picture such as the dependent and independent variable. Furthermore, the features within the diagram correspond to those of the represented content. They show arbitrary structures which are highly conventionalized (Schnotz 1994). On the contrary, images, drawings, and sketches belong to realistic pictures, in which representing and represented features are equivalent. Dimensions can vary from realistic to schematic and from concrete to abstract. Schemas are categorized very heterogeneously in literature. They are present as realistic pictures close to reality or as schematic contour drawings (cf. Cheng and Gilbert 2015; Schnotz 1994). If the conventions are required for understanding schemas, they may be defined as drawings of different abstraction and closeness to reality. In this case,

they can be assigned to the group of logical depictions (Griffard 2012). Otherwise, schematic drawings are characterized by realistic, even iconic, domain-specific, and convention-based elements (Weidenmann 1994). Such schemas are designated as semi-realistic representations and point to ascending abstraction, for example, "complex process diagrams" (Griffard 2012).

Representational Competence and Integration of MERs

Dealing with MERs requires visualization competence. "Representational competence" summarizes the mutual translation when handling with MERs and is defined as (Kozma and Russell 2005, p. 131):

> a set of skills and practices that allow a person to reflectively use a variety of representations or visualizations, singly and together, to think about, communicate, and act on chemical phenomena in terms of underlying, a perceptual physical entities and processes.

The study by Florian (2012) shows more than 42% of investigated tasks in the Abitur examination demanding an information extraction or construction of a figure as approach. It implies abilities like interpreting, constructing, translating, and evaluating representations (cf. Ainsworth 1999; Kozma and Russell 1997; Rönnebeck et al. 2006). Interpreting means extracting information from one or more presented depictions and translating this information into another (e.g., text) (Mayer 2002). The construction process demands to create a new representation independently. The translation processes require comprehension in processing information and conversion between different representations (Ainsworth 1999; Schönborn and Bögeholz 2009). The integration of MERs and therefore the learning success consists of an organizing and integrating process and leads to a coherent mental model (Mayer 2005; Schnotz and Bannert 1999). It is necessary to consider principles in cognitive psychology regarding integration as well as working memory (Mayer 2005; Paivio 1986; Sweller and Chandler 1994). Further critical aspects are previous knowledge, competent reading comprehension, and willingness for deep semantic processing (Cox 1999; Schnotz et al. 2011; Seufert 2003). Students develop heightened conceptual knowledge and gain deeper understanding of specific content when working with pictures and texts (Ainsworth 2006; Hubber et al. 2010). MERs can facilitate learning and usage of higher-ranked strategies for solving problems. Different research findings document this advantage of MERs (cf. Ainsworth et al. 2002; Griffard 2012). In contrast, learners often struggle when dealing with MERs, especially where the information of text and picture is combining and integrating (Brünken et al. 2005; Levie and Lentz 1982).

Schönborn and Bögeholz (2009) complement the described processes of interpretation, construction, and translation by different types of representation and

define these as level of abstraction of a representation. A stronger focus on biology is given by emphasizing the organizational levels in biology (cf. Kozma and Russell 1997). The "cube model" by Tsui and Treagust (2013) presents all the components mentioned, distinguishing three dimensions: (1) types of representations, (2) levels of representations, and (3) domain knowledge of biology. The model presents a fundamental basis for describing learning processes when dealing with MERs and developing representational competence. Acquiring representational competence takes time and practice, while presenting factual knowledge allows for fast growth of knowledge (cf. Kozma and Russell 2005; Nitz et al. 2014). However, the three components from the cube model illustrate learning with MERs without cognitive processes. Previous studies often either concentrate on one type of representation or refer to specific content of a biological topic (Lachmayer 2008; von Kotzebue and Nerdel 2015). Lachmayer (2008) investigated the extraction of information and construction based on diagrams for the topic of photosynthesis. Von Kotzebue and Nerdel (2015) pick up these study findings and analyze the integration process when dealing with diagrams. The results of the study showed a significant difference between *integration by information extraction* and *integration by construction*. The structural model for visualization competence (Wafi and Wirtz 2016) focusses on connections of multiple representations, text-picture integration on the one hand and picture-picture integration on the other. This frequent change in representations describes especially translation and transformation when combining more than two forms of representation. In a qualitative study, Maier et al. (2010) developed and validated a categorical system for interdisciplinary task analysis considering different forms of representations of knowledge. There are certain tasks with *one form of representation*, *integrating different forms of representations*, and *integration and transformation* of knowledge. Current research in biology education shows no appropriate competence models concerning the integration of MERs. Neither there are competence models providing statements about the difficulties when shifting between different representations, considering fundamental design features and conventions but also the biological context. Only this can meet the needs of diverse forms of representation in classroom. Against this background, we took into account national and international standards, curricula, and school benchmarking studies but also general psychological and didactical theories and models.

Based on this, the competence model postulates three components for integrating MERs. The dimension *integration of MERs* describes the knowledge about central processes in solving tasks with representations and consists of three subcomponents: *integration by information extraction and interpretation* (MERI), *integration by construction* (MERII), and *translation and transformation of different scientific representations* (MERIII). In addition, the competence model considers three different *biological task contexts* and two *types of representation*.

A Competence Model Addressing the Biology-Specific Understanding of Pictures

In biological science education, competencies are defined (Kampa 2012, p. 43):

> as learnable, cognitive, context-specific dispositions of performance enabling the solution of biology-related problems in variable situations.

The competence model focusses on the cognitive processes for the integration of MERs in different biological contexts and using different types of representations. As a result, cognitive as well as content-based features will be considered. The dimension *type of representation* consists of two forms of representation. Diagrams are still highlighted, especially the part of MERIII shall be analyzed. The focus is on diagrams in different biological contexts and not just one specific subject content. The second component of this category are schemas. The inclusion of this type of representations contributes to classifying and defining realistic and logical pictures. The dimension *biological task context* describes contexts (Muckenfuß 2004, p. 64):

> as topics or topical aspects of a special subdomain (…), allowing for development of a well-defined scope of the scientific world of ideas.

Those are confined to the used special content within an exercise. In addition, these contexts relate to more or less contextualized problem situations, which serve the simplifications and clarification of concepts and therefore facilitate the application of subject contents (cf. Finkelstein 2005; Gilbert 2006; Muckenfuß 2004). The competence model refers to the model of van Vorst et al. (2014), which combines categories of contextual features based on theory. According to that, contexts should warrant authenticity, be sufficiently complex, relate to everyday life, deal with extraordinary phenomena, and ensure relevancy of treated contents. The model comprises three different biological task contexts: ecology, metabolism, and genetics. These contents play an essential role in the choice and the requirements for the written Abitur in Germany (Florian 2012). Besides, the contents exhibit a high relevance for the curricular at school and university.

Accordingly, the developed tasks are embedded into authentic everyday situations and present the subject content in a superior problem definition (cf. Finkelstein 2005; van Vorst et al. 2014). Figure 1 presents the competence model.

Aim of the Study and Research Questions

So far, it has not been investigated what forms of integration of MERs exist in general, and in what way representational competence depends on the biological context, or rather how it is influenced by other factors. This background leads to the question which aspects of integrative text-picture processing provide information concerning difficulties and complexities of tasks with MERs. To address this question, a competence model was created for dealing with MERs, which focuses
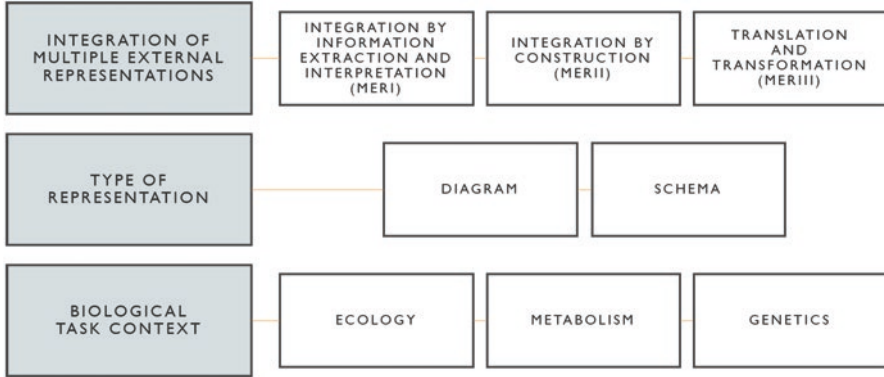
Fig. 1 Competence model addressing the biology-specific understanding of pictures

on the integration of verbal and visual representations in different contexts in order to enhance standardization of representational competence in biological science.

As a first aim, test tasks are developed by the means of the competence model. The tasks operationalize the integration of MERs (MERI, MERII, and MERIII) in the subject of biology using different types of representation (diagram, schema). Afterward the aim is to verify empirically, validate the hypothetical model, and identify further influence factors for item difficulty. These aims lead to the following three research questions:

1. Are different skills required for solving integration tasks, i.e., what kind of different competence constructs can be empirically confirmed concerning the integration of MERs?
2. Which influencing factors can be identified that generate difficulty in MER tasks in different fields of school biology?
3. Which personal data can be diagnosed with regard to competence profiles when dealing with MERs in different biological contexts?

Methods

Sample

Participants of the study were 548 first-year university students (48% female, 52% male). The mean age was $M = 21$ years ($SD = 2.5$ years). The study investigates students from different academic fields to achieve a high variance in the sample. Table 1 presents the distribution of the sample. It was assumed that the participants are familiar with the content as they have recently graduated from high school (German Abitur). In this context, it was important to find out if the tasks are independent of prior knowledge because the main focus of the study is the integration of MERs.

Table 1 Distribution of the students from different academic fields

Academic field	Number
Teacher training biology	84
Teacher training mathematics (and biology)	35
Life sciences	145
Engineering	168
Mathematics	101
Other	15

Table 2 YSD for the distribution of the test items in the test booklets

B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12
1	2	3	4	5	6	7	8	9	10	11	12
2	3	4	5	6	7	8	9	10	11	12	13
3	4	5	6	7	8	9	10	11	12	13	1

Aside from the academic field, the study collected other demographic data like age, sex, and most recent grades in biology and mathematics in school in a self-disclosure.

Test Design and Elicitation Instrument

To investigate the three research questions, a booklet of test items was created. These booklets should cover the widest possible range of content and take into account a reasonable test load for the participants of the study. The item pool consists of 36 test items, chosen from the pilot study examining the model assumptions (cf. Table 2). The selected items have been proven suitable based on content and statistical parameters. We clustered three test items each in an open-answer format. We arranged the resulting 12 clusters in the test booklets based on a Youden square design (YSD) by Frey and Annageldyev (2015). The clusters appear in equal numbers in all test booklets ensuring a connection between the booklets. One booklet contains three clusters with nine test items in total. This allows us to give all test persons a realistic chance for answering. Each booklet includes two identical clusters of its precursor (e.g., test booklet four contains clusters 4, 5, 6 and booklet five contains clusters 5, 6, 7; therefore, these two booklets have clusters 5 and 6 in common). The clusters' positions within the test booklets are rotated in a way that each position is represented exactly once. The position of the test items within the clusters is not rotated (cf. Table 2).

One can therefore assume that there is a reasonable distribution, connection, and permutation of the test items in all 12 used test booklets. We choose three valid test

Table 3 Distribution of the test items to the components of integration of MERs, considering type of representation and biological task context

Cluster	Item 1	Item 2	Item 3	Cluster	Item 1	Item 2	Item 3	Type
1	Eco I	Gen II	Eco III	2	Met I	Met II	Met III	D
3	Gen I	Eco II	Gen III	4	Met I	Met II	Met III	S
5	Gen III	Eco I	Gen II	6	Met III	Met I	Met II	D
7	Eco III	Gen I	Eco II	8	Met III	Met I	Met II	S
9	Eco II	Gen III	Eco I	10	Met II	Met III	Met I	D
11	Gen II	Eco III	Gen I	12	Met II	Met III	Met I	S

items for each subcomponent of the dimension *integration of MERs* (MERI, MERII, and MERIII) and the dimensions *type of representation* and *biological task context*. In total, we used nine test items with diagrams in the context ecology and nine test items with schemas in the context genetics. To maintain the comparison within the biological task contexts anyways, both, diagrams and schemas, have been presented within the context of metabolism. This procedure allowed a distribution of $n = 12$ test items per subcomponent of the dimension *integration of MERs*, which is metrologically satisfactory. In clustering attention was paid to a balanced range of difficulties and ensured that each test booklet contained at least one cluster from the context metabolism and that all three components MERI, MERII, and MERIII represented all three biological task contexts. Table 3 presents the exact arrangement of the three model dimensions among the test items.

Figure 2 shows an exemplary item (PKU08MERIS) for *integration by construction* (MERII) with a schema as *type of representation* and genetics as *biological task context*.

Implementation of the Study

We conducted a pilot and a subsequent main study. The aim of the pilot testing was examining the constructed test items according to the competence model and designing a categorical framework for coding open test exercises which we elaborated using the qualitative content analysis (Mayring 2000). We evaluated the framework by two independent raters and coded the open test items by means of a coding manual (Cohen's kappa $\kappa = 0.80$). In the pilot and main study, the competence test was done in writing, using the 12 test booklets (cf. Table 2). The test time was 45 min in total. At least 95 and up to 131 students answered each of the 36 test items. We analyzed the data with one- and multidimensional Rasch models to determine forms and dimensions of representational competence and to review the postulated model structure.

Phenylketonuria (PKU) is a hereditary disease. It leads to metabolism disorders and eventually severe mental disability. Diseased people lack the enzyme degrading the amino acid phenylalanine to tyrosine. This results in heightened phenylalanine levels and simultaneously in tyrosine deficiency in the blood. PKU is inherited autosomal recessive, viz. diseased people have the genotype aa, healthy people the genotype AA. Carriers of the disease are heterozygote, they have the genotype Aa.

The family tree shown below belongs to the family Huber and shows the inheritance of PKU throughout the generations.

Analyze and interpret the family tree of family Huber considering the genotype Aa. Therefore, assign the genotypes AA, Aa or aa to the persons 1-12 and fill out the boxes below.
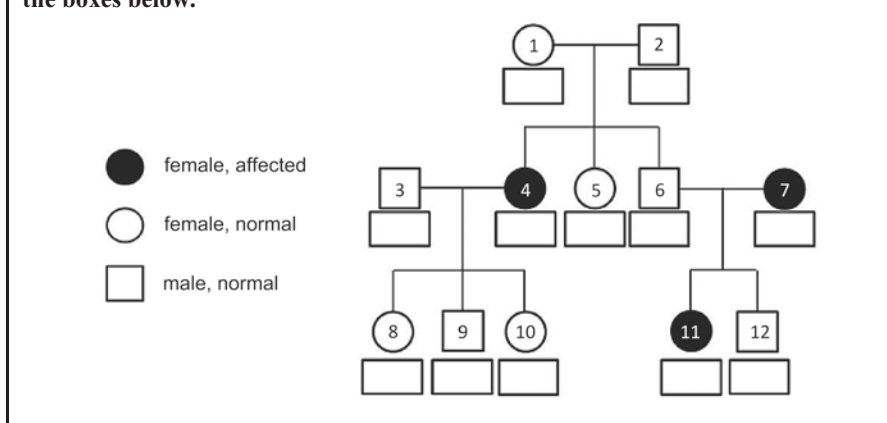
Fig. 2 Example item: the metabolic disorder phenylketonuria

Data Analysis

The specification of individual competence can be estimated with the Rasch model. This method makes it possible to compare the results of the participants of the different test booklets. The evaluation of the data is based on models of item response theory (IRT). The data has been analyzed by IBM SPSS Statistics 22 and ACER ConQuest. ConQuest models the probability of a correct answer by a logistic function. With regard to the research questions 2 and 3, the aim was to figure out with which probability a person knowing the item difficulty and person's ability solves an item correctly or not (Bühner 2011). In addition we consulted the Wright Map for examination of the range of abilities. The Wright Map plots the person parameters and the item difficulties on a joint logit scale. The determination of reliability of a test is made on EAP/PV reliability whose value equals the Cronbach's alpha in classical test theory (Rost 2004). We determined the quality of single items in the Rasch models using a fit statistic (Moosbrugger 2012). As reference, we consulted the weighted mean square (wMNSQ) with an ideal expectation of 1.0 (Bond and Fox 2007). Values between 0.8 and 1.2 indicate that the items are

Rasch-compliant (ibid.; Wright and Linacre 1994). Therefore, we even checked the T value as an additional inference statistical assessment.

We used multidimensional Rasch models measuring various forms of a competence. According to the framework of our competence model for integrating MERs, we assumed that the best fit persists empirically by the three-dimensional model consisting the components MERI, MERII, and MERIII. There are several possible measurement models: (1) one-dimensional model representing the integration of MERs with precisely one dimension; (2) two-dimensional model assigning the 12 test items of the dimension MERIII to either dimension MERI or the dimension MERII, in this case, the assignment followed by output text (assignment to MERI) or picture (assignment to MERII); (3) two-dimensional model distinguishing between the integration with diagrams and with schemas; and (4) three-dimensional model differentiating the integration amidst the contexts of ecology, metabolism, and genetics. The model fit must be verified concerning the interpretation of the competence test. Therefore, we calculated different Rasch models and, based on the data, analyzed different information criteria (AIC, BIC, CAIC) with regard to their adjustment (Rost 2004). We conducted further regression analyses to examine all relevant variables influencing the item difficulty to answer research question 2.

Results

Multidimensionality and Representational Competence

The fit statistics of the item parameter of the one-dimensional model are satisfactory (0.80 < wMNSQ<1.20, T < 1.96, item separation reliability >0.97) and correspond to the quality criteria which are customary in the probabilistic test theory (Rost 2004).

The model with the lowest value of the BIC shows the best adjustment to the empirical data relating the final deviance (1D: 5250.84, $2D_{MER}$: 5242.51, $2D_{type}$: 5247.92, $3D_{MER}$: 5242.98, $3D_{con}$: 5241.36) to the number of parameters (1D: 37, 2D: 39, 3D: 42) and considering the sample size (N = 548). With regard to research question 1, the findings support the two-dimensional competence model, where the test items of the component MERIII were divided between MERI and MERII. Also regarding the information criteria (AIC, BIC, CAIC), the two-dimensional model shows a better adjustment than the other possible models for integration of MERs (BIC_{1D}: 5352.18, BIC_{2DMER}: 5349.32, BIC_{2Dtype}: 5354.73, BIC_{3DMER}: 5358.01, BIC_{3Dcon}: 5356.39).

Aside from that, we calculated the latent correlations between the individual dimensions. The latent correlation is $r = 0.56$ between the components MERI and MERII. This value is below $r = 0.90$, and so the answer is also the $2D_{MER}$-model (Bond and Fox 2007). It allows us to assume two separate constructs for the integration of MERs. Figure 3 depicts the Wright Map distributing the person parameters and the item parameters at a two-dimensional Rasch model ($2D_{MER}$).

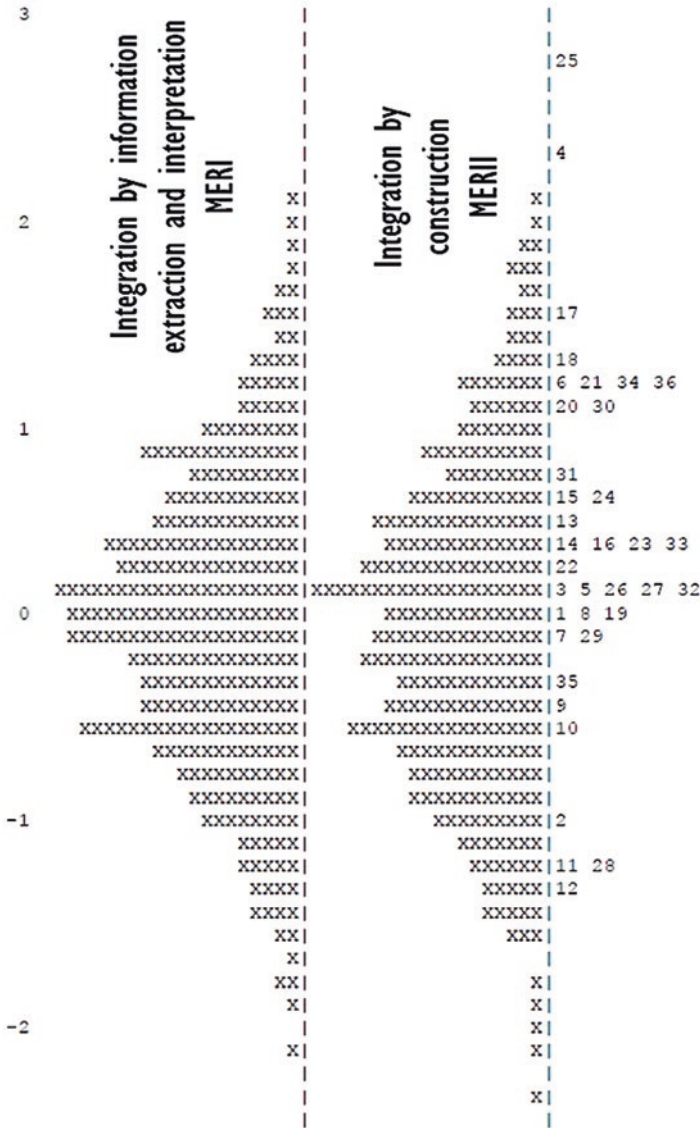**Fig. 3** The Wright Map shows person ability and item difficulty on the same logit scale

Item Analyses

With regard to research question 2, we investigated the influence of various task characteristics on the item difficulty. For this, we used the item difficulties determined by one-dimensional Rasch scaling. We examined if the medium item difficulty of the defined constructs in the competence model (integration of MERs,

Table 4 Item difficulty within the competence model and focus on dealing with MERs and biological contexts

	M	*SD*		*M*	*SD*
MERI	0.05	0.87	*MERII*	0.79	0.71
MERI_metabolism_D (n = 6)	0.56	1.20	*MERII_ecology_D (n = 4)*	1.04	1.11
MERI_metabolism_S (n = 6)	0.14	0.39	*MERII_metabolism_D (n = 3)*	1.02	0.59
MERI_ecology_D (n = 5)	−0.73	0.52	*MERII_metabolism_S (n = 3)*	0.82	0.46
MERI_genetics_S (n = 3)	−0.97	0.45	*MERII_genetics_S (n = 6)*	0.50	0.59

type of representation, biological task context) is statistically different. Descriptive analyses relating to the item difficulty are shown in Table 4.

The analysis shows a significant difference in item difficulty between the components MERI and MERII ($t(34) = -2.775$, $p < 0.01$, $d = 0.74$). The value of the medium item difficulty of MERI tasks is $M = 0.05$ ($SD = 0.87$) and that of MERII tasks is $M = 0.79$ ($SD = 0.71$). Hence, the most difficult tasks to resolve were those requiring an integration by construction (MERII).

The multiple regression analysis for the prediction of the task difficulty shows that the *integration of MERs* is the strongest predictor for representational competence. Both components, MERI and MERII, have a significant influence on item difficulty ($F(4,31) = 4.250$, $p < 0.01$, $R^2 = 0.35$, $R^2_{corr.} = 0.27$; MER: $t = 3.594$, $p < 0.01$). The component *type of representation* is not statistically relevant. Regarding the *biological task context*, the results reveal a significant influence only on the item difficulty for genetics ($t = -2.666$, $p < 0.05$), but not for the contexts ecology or metabolism.

Competency Analyses

The person parameters of the two-dimensional Rasch model will be required to explain the differences in competence in performing tasks with MERs and between students of different academic fields. This leads us to answering research question 3. The findings indicate that there are differences in person abilities ($z = -8.783$, $p < 0.001$, $N = 545$, cf. Fig. 4) between the components MERI ($M_\theta = -0.01$ Logits, $SD = 0.05$) and MERII ($M_\theta = -0.65$ Logits, $SD = 0.05$).

Moreover, we recorded significant differences in person abilities between tasks with diagrams or schemas ($z = -4.574$, $p < 0.001$, $N = 547$). Average person ability for tasks with diagrams is $M_D = -0.52$ ($SD = 0.05$) and for tasks with schemas is $M_S = -0.19$ ($SD = 0.05$). The one-way ANOVA with repeated measures shows significant differences in the achievement of students regarding the biological task context ($X^2(2) = 12.695$, $p < 0.001$, $N = 521$). Average person ability amounts $M_{Eco} = -0.36$ ($SD = 0.05$) for ecology, $M_{Met} = -0.44$ ($SD = 0.06$) for metabolism, and $M_{Gen} = -0.09$ ($SD = 0.05$) for genetics. The Bonferroni method for pairwise comparison shows that the context genetics differs from the context ecology as well

Fig. 4 Person abilities integrating MERs (M = mean square)
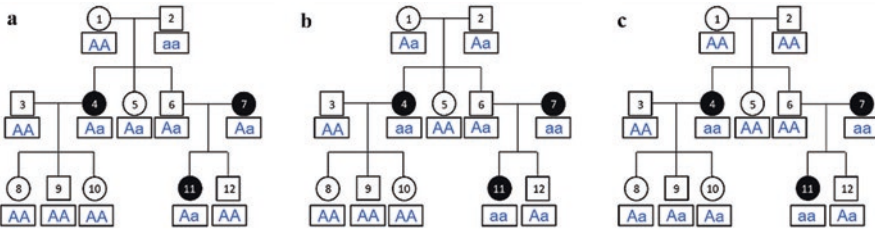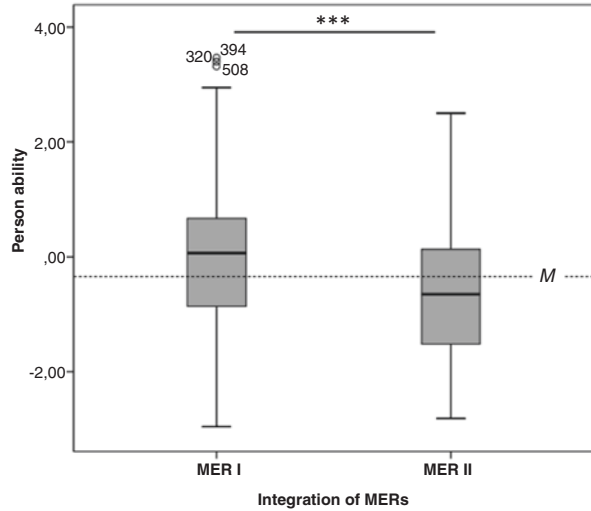
Fig. 5 (**a–c**) Examples of answers for the test item PKU08MERIS

as from the context metabolism. The difference between the context ecology and metabolism is not statistically significant. Significant differences in the degree programs only show up between life sciences and engineering.

Examples of Answers

We found out that students have problems on the level of the genotype (cf. Fig. 5).

In the first example, one sees that the test person had difficulties in matching the genotypes. This applies both to reading the data and interpreting the given symbols. In the second example, the concept of the recessive inheritance has been understood. This participant assigned healthy people and carriers of the disease PKU to the right symbols. However, the participant was unable to allocate these points to persons 8, 9, and 10 in Fig. 5b. In the third example, it is unclear which of the concepts the test person has understood. This is particularly noticeable regarding the incorrect assignment of the genotypes to persons 1 and 2.

In the framework of a qualitative study, we analyzed the answers of the sample examined. The following are examples of reasons of different test persons for the assignment of the genotypes:

> Recessive means that a disease can be inherited although the trigger is not part to the dominant genes of the parents. Carriers and infected persons are exclusively women. Children do not have to fall ill, only in the case of a dominant gene.

As the preceding example illustrates, the connection between genotype and phenotype is not clear. The understanding of a recessive inheritance could not be transferred to the family tree. One of the reasons for this is that the change from phenomenal level does not succeed to the distribution of alleles:

> No. 4 refers to an infected person and the person carries the genotype aa. No. 3 refers to the father, which has the genotype AA. The children may have the genotype AA or Aa. We can say that the children are healthy, because PKU is inherited recessively. However, a child that has the genotype Aa can have children with the genotype aa, if this person mate with a person having genotype Aa or aa. No. 6 carries the genotype Aa and is, therefore, healthy. Person No. 7 has genotype aa. The descendants have the genotype aa (No. 11) and Aa (No. 12).

This example shows the correct identification and assignment of diseased children. However, the connection has not been understood between carriers of the disease and healthy persons, viz., there is a lack of understanding at genotype level and at inheritance of alleles.

> Nos. 1 and 2 and No. 6 are carriers of the disease. Nos. 3 and 4 only have healthy children. For this reason, No. 3 must have the genotype AA.

One can see that the connection is incompletely understood only between the carriers of the disease and healthy persons, viz., there is a lack of understanding of the genotype of diseased persons with the alleles aa, and therefore children of diseased persons are always carriers of the disease.

Discussion and Practical Implications

The study focused on learning with MERs, i.e., with more than one representation, and integration of these MERs in different biological contexts. The findings presented above indicate that in order to develop representational competence, various competences interacting with MERs are crucial.

The results confirm two distinguished cognitive processes: (1) *integration by information extraction and interpretation* (MERI) and (2) *integration by construction* (MERII). This differentiation is in line with the findings of previous studies regarding the output of a task solution. Thus, the information extraction from a diagram with the output text represents a different ability from constructing a diagram (e.g., Lachmayer 2008; von Kotzebue and Nerdel 2012). This study also found typical difficulties in dealing with diagrams such as choosing the wrong diagram type, wrong scaling, or mixing up dependent and independent variables.

The picture-based construction (MERII) is particularly difficult for students. We found that the partial competences, MERI and MERII, affect item difficulty, whereas the biological context is less critical than the demand of mapping between representations itself. We revealed significant differences between the two types of representation (diagram, schema). If learners do not understand that the energy at different nutritional levels is illustrated by the bar width, they will struggle more with interpreting this form of representation (cf. Ziepprecht 2016). The study of Schnotz et al. (2011) shows that the degree of abstraction of a representation affects the difficulty of a task and consequently tasks containing realistic pictures are more difficult to solve. Brandstetter-Korinth (2017) determined the contrary by demonstrating that learners understand better realistic pictures than abstract variations. Therefore, many components play a role, such as abstraction, convention, as well as the used elements and their relation to one another. The presented results also show that students often use only one representation and the actual text-picture integration is missing. This indicates that there is a lack of learning possibilities and application situations distinguishing various types of representations (cf. McElvany et al. 2010). We found significant differences between tasks in the biological context metabolism and genetics as well as between ecology and genetics. Contrary to the expectations that tasks in the context genetics being particularly hard to solve because they demand special prior knowledge of conventions, these tasks have been solved most successfully. The participants answered the tasks in the context metabolism less successful followed by tasks in ecology. One reason for this might be the increased requirement of physical and chemical concepts applied in a biological context. This transfer seems to be the obstacle. Dealing with MERs requires specific abilities from learners. The study of Ainsworth et al. (2002) showed that working on a task is influenced by the type of representation and the degree of abstraction of a logical picture. Our study confirms these results as well. Therefore, the text-picture integration will only be successful if every representation is understood individually, related to one another, and will integrate into a mental model (cf. Cheng and Gilbert 2015; Mayer 2014). The findings only show a significant effect on item difficulty for the biological task context genetics. It is noticeable that mathematics students show the highest ability values in these tasks. This opens up the question to what extent the knowledge and the comprehension of conventions of a specific figure type reduce item difficulty. And on the other side what influence has mathematical (prior) knowledge.

We can offer practical recommendations for higher education, teacher training, and school practice. The developed competence model can sensitize education experts and (prospective) teachers to practice continuously the abilities for dealing with MERs in different contexts and to rehearse design principles (cf. Kozma and Russell 2005; Wafi and Wirtz 2016). The construction of diagrams and schemas should be promoted reflectively and interdisciplinary using different approaches. The findings of the study show that the integration of MERs is less dependent on the content but on the reading and translation skills. As a result, it is necessary to work out and to relate to the complementary information explicitly. For that, teachers can use integration assistances and cognitive processing approaches that

help to clarify the integration for learners with learning difficulties step by step (e.g., Corradi et al. 2012). Competency-based tasks promote communicative skills. They can also be used for the diagnosis of and the feedback about difficulties in handling representations (e.g., Beck and Nerdel 2016). The presented competence model provides information about dimensions and manifestations of biology-specific competences in dealing with MERs. The model closes the research gab by focusing on text-picture integration and discussing requirements of upper secondary level. The analysis of the competence distribution leads to possible levels in competences within the MER integration. These can be defined post hoc and validated within the framework of continuing research. The cognitive demands can be specified within the MER integration more precisely by assigning test items to competence levels. This allows a subsequent competence-related feedback. Therefore, differentiated evaluation becomes possible, which creates favorable conditions for learning and motivation (Harks et al. 2014). Regarding the figure type, further analyses are necessary. They should be linked to existing research about logical pictures and abstract schemas in different biological contexts (Ainsworth 2006; Brandstetter-Korinth 2017; Lohse et al. 1994) as well as analyzing highly conventionalized pictures separately in static and dynamic pictures (e.g., Ainsworth et al. 2002; Wu et al. 2015). Such investigations highlight the influence of representational conventions on competence levels. Finally, the competence model will be applied interdisciplinarily if the technical context is varied systematically across all three sciences and at constant kind of switching representations. For this, studies might be ideal which collect data collectively by all three sciences and by mathematics education and which foster interdisciplinary cooperation in stem education at university.

We hope this chapter is useful in promoting lecturers' awareness of the benefits of integrating MERs to student learning. In this regard, this chapter should contribute toward the development of relevant learning materials in different academic fields.

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Heat Angels and Paper Cups: Pupils' Use of Metaphoric Relations When Engaging Thermal Cameras to Investigate Heat

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Embodied Cognition and Metaphoric Relations in Understanding

Our everyday language is filled with all sorts of metaphoric relations (e.g. analogies, metaphors and metonyms). Metaphoric relations – the idioms in which we talk about one phenomenon in terms of another – are linguistic units that are an important constituent in the way we reason about and understand the world around us (e.g. Grady 1997; Lakoff and Johnson 1980; Johnson 2007). Our metaphoric relations are a consequence of the way the physiology of the human body and brain interacts with what we perceive as reality, where recurring sensory experiences form the basis for neural structures between everyday events and abstract concepts (e.g. Lakoff and Johnson 1980, 1999; Johnson 2007).

Lakoff and Johnson (1980) term such physical and cultural everyday events "natural kinds of experience" (p. 117). We use these natural experiences to structure and conceptualise metaphoric descriptions of phenomena (e.g. quantity in terms of verticality, similarity in terms of proximity, or arguments in terms of war) through primary metaphors (e.g. Grady 1997; Lakoff and Johnson 1999; Johnson 2007), which in turn structure the formation of other more complex concepts (e.g. love in terms of a journey) that expand our ability for abstract reasoning (e.g. Grady 2005; Lakoff and Johnson 1999). Although we take these ubiquitous metaphoric relations

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between sensory experiences and abstract concepts for granted, from an embodied cognition perspective, they serve as the foundation for reasoning and understanding; they represent the "metaphors we live by" (Lakoff and Johnson 1980).

We spend our lives interacting in a physical world that exhibits constant motion as part of human behaviour. In turn, we tend to conceptualise abstract phenomena such as love, time, life, death, economics and energy in terms of movement and/or human activities (Lakoff and Johnson 1980, 1999; Johnson 2007; Wiser and Amin 2001). These conceptualisations are manifested in expressions like "we are *running* out of time" or "she *boiled* with rage", where the metaphors *Time is a Resource*[1] and *Anger is Heat* are central to our conceptualisation thereof (Lakoff and Johnson 1980, Johnson 2007).

Following the assumptions formulated above, metaphoric relations are based on everyday sensorimotor experiences. This implies that conceptualising movement is a consequence of how we perceive motion (Johnson 2007). Doing so gives rise to three necessary conditions for conceptualising a phenomenon in terms of motion:

- Since movement is only possible in a physical space, conceptualisation of a phenomenon in terms of motion requires imposing mental boundaries onto sensory experiences, thus separating parts of an experience from the whole experience (Lakoff and Johnson 1980; Johnson 2007; Grady 2005).
- Since movement can only be perceived when a physical object is present, conceptualisation of a phenomenon in terms of motion requires treating the bounded parts of an experience as separate mental entities. This leads to the formation of ontological metaphors such as an *Object is a Container* or an *Object is a Substance* (Lakoff and Johnson 1980; Johnson 2007; Grady 2005).
- Since all movement has implicit qualitative dimensions, i.e. the amount of force causing the movement, the velocity of the movement, the direction of the movement and the trajectory of the movement, conceptualisation of a phenomenon in terms of movement requires quantifying each qualitative dimension in relation to the bounded elements of the experience (Lakoff and Johnson 1980; Johnson 2007).

When all three conditions are fulfilled, we are able to conceptualise phenomena such as *heat* in terms of movement using metaphors such as "could you turn *up* the heat" or "the temperature is *gradually increasing*". In some situations, new metaphoric relations between already existing metaphoric relations are formed as the sensory elements that we perceive while interacting with the environment add qualities to the abstract target concepts. As a result, our abilities to conceptualise abstract phenomena are expanded (Grady 2005). While these events reoccur over time, novel metaphoric relations strengthen relationships between initial sensory experiences and corresponding abstract concepts (Lakoff and Johnson 1999). Thus, forming new metaphoric relations occurs in relation to already existing metaphorical structures. Moreover, as part of interpreting abstract concepts such as time, economics or physics, we are also dependent on *blending* different natural (sensory)

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[1] Title case letters are used in the text to depict metaphoric relations.

experiences into more complex metaphoric relations expressed in language, reasoning and behaviour (Lakoff and Johnson 1980, 1999; Johnson 2007; Grady 2005). As a consequence, our more advanced and complex conceptual metaphors, such as those manifested when reasoning about a physics problem, for example, are grounded in a blend of previous physical and/or cultural experiences (Lakoff and Johnson 1980, 1999).

According to Grady (2005), at least two prerequisites need to be met to form conceptual metaphors. Firstly, a conceptual metaphor has to contain a sensory (the *source*) and a nonsensory (the *target*) element. Secondly, both sensory and nonsensory elements need to share properties of the same basic metaphorical structure. For example, a sensory experience of movement provides meaning in relation to properties of physical space; the objects involved and the quality of movement (Johnson 2007; Lakoff and Johnson 1999). It then becomes possible to form conceptual metaphors relating colour to movement by utilising metaphors such as COLOUR IS AN ENTITY that structures our conceptualisation of colour in such a way that it "moves" along a linear colour scale.

In cases where the above conditions are not fulfilled, novel conceptual metaphors will not be formed. However, metaphoric relations in the form of metonymies such as "could you get me that Shakespeare from the shelf?" or "the Vietnam protesters marched through town" could still be used as referential tools that allow for interpretation of one element as standing for another (Frisson and Pickering 1999; Lakoff and Johnson 1980; Kövesces 2013). Metonymies – *Part for the Whole relations* – are therefore a significant component of both our everyday language and actions (Lakoff and Johnson 1980) and can serve as a source for the formation of novel metaphors (Kövesces 2013).

Overall, metaphor theory as communicated by theorists such as Lakoff and Johnson (1980, 1999), Johnson (2007) and Grady (2005) reflects the embodied perspective of cognition, which asserts that conceptualisation is a result of the way the body and the brain "function in interpersonal relations and in the physical world" (Lakoff and Johnson 1999, p.37). Our interaction with the world provides the origin for forming metaphoric relations that can be analysed to explore how their structural components contribute to understanding. In this regard, there is growing work in applying embodied cognition and metaphor as a perspective for exploring how students conceptualise and reason about physical (e.g. Amin et al. 2015), chemical (e.g. Myers 2008) and biological (e.g. Niebert et al. 2012) phenomena in education.

Understanding Thermal Phenomena

Decades of science education research, across all levels, has demonstrated various challenges around pupils' understanding of thermal phenomena such as heat (e.g. Chu et al. 2012). One salient obstacle is the difficulty in differentiating between heat and temperature (Erickson 1979). In this case, there is a large volume of evidence showing that pupils interchange "heat" and "temperature" in their reasoning about

thermal phenomena in utterances such as "temperature measures heat" (Wiser and Amin 2001). Another difficulty is misinterpreting the temperature of substances such as metal that feels cold to the touch, to be inherently "colder" than other materials such as wood. The potential source of these challenges can be ascribed to various aspects. For example, communication of ideas associated with heat makes complete sense in everyday language (e.g. "you're letting the heat out of the window" or "don't get so heated in the debate") yet carries a completely different meaning in physical science (e.g. "heat is an energy transfer") (cf. Romer 2001). Furthermore, in comparison with other substances, metals at room temperature really *do* feel cold to the touch, and student difficulties associated with lower temperatures being assigned to the latter reflect the significant role of sensory experiences – and the manner we talk about them – in the conceptualisation of abstract ideas such as heat and temperature.

Since thermal science is an important area in many international curricula and a topic with multiple real-world applications, it remains crucial for science educators to explore students' expressions of heat-related phenomena. Recent science education research has highlighted the role of metaphor and language in students' understanding of thermal phenomena. For example, in an interview study with university physics students, Brookes and Etkina (2015) showed that solving heat-related problems is largely determined by the way students *themselves* conceptualise the term "heat" and that students often talk and reason about thermal systems in terms of heat "containers". In other work, Jeppsson et al. (2015) have explored how university students use conceptual metaphors in reasoning around heat and entropy. Their study found that solving thermodynamic problems requires *coordinating* various propositional (e.g. natural language) and non-propositional (e.g. sensory experiences) entities that are often mediated by implicit metaphorical structures. Such studies demonstrate the importance of investigating the influence of language and metaphor in students' understanding of educationally important thermodynamic entities such as heat.

Exploring Heat with Thermal Cameras

One means for addressing the challenges around students' conceptualisation of thermal phenomena is offered through infrared (IR) imaging technology. Hand-held IR cameras (also referred to as thermal cameras) detect electromagnetic radiation emitted from the surfaces of objects. In turn, the corresponding temperatures of object surfaces are mapped to a dynamic real-time coloured visualisation of the surroundings across a respective temperature range. Consequently, a pseudo-colour scale enables humans to intuitively perceive warmer (red) and cooler (blue) surfaces (see Figs. 1, 2 and 3). In turn, engaging IR cameras as a window through which to view otherwise unseen thermal properties provides access to visual representations of heat transfer processes (Vollmer et al. 2001).

Fig. 1 Three peers observing the efficiency of their modelled paper cup thermoses using a thermal camera. The pupil in the centre directs the camera towards the thermoses (left). A corresponding thermal image viewed on the camera display and captured by the group during the activity (right)
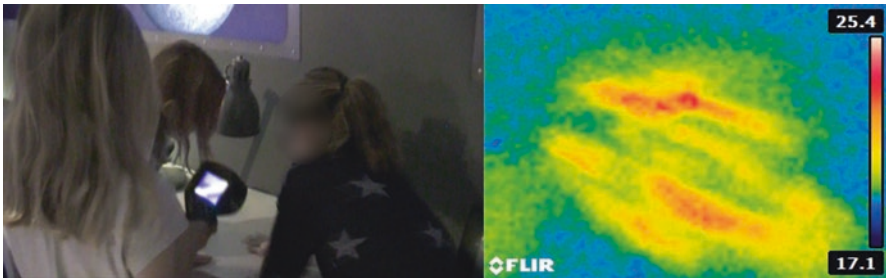
Fig. 2 A pupil group making hand contact with a table surface during the exploration activity. The pupil in the centre directs the camera towards a peer's hand, while her fellow peers rub the table surface (left). A corresponding thermal image captured by the pupils during the activity (right)
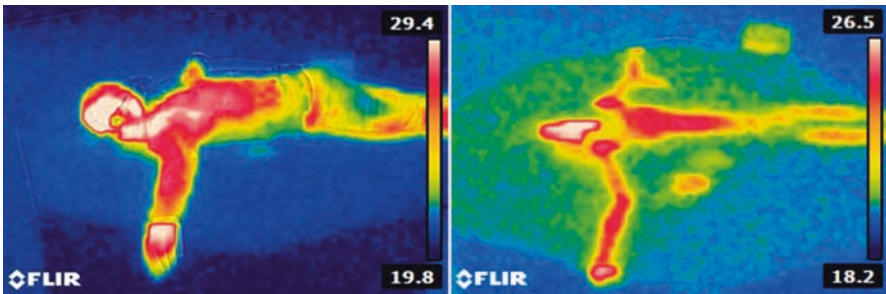
Fig. 3 A thermal image of a pupil lying on a cloth-covered seat in an attempt to transfer heat from her body to the object (left). A thermal image of the resulting, otherwise invisible "heat angel" signature generated on the cloth surface (right)

Apart from industrial and commercial application, work by Xie (Xie 2018; Xie and Hazzard 2011) recognised the pedagogical potential of thermal cameras as a tool for visualising thermodynamic phenomena. The intuitive nature of the visually augmented thermal display lends itself as a candidate for inspiring various discovery- and inquiry-based learning opportunities. Our own research across multiple levels of education (e.g. Haglund et al. 2016a) has suggested that thermal cameras can serve as a catalyst for generating cognitive conflicts (Schönborn et al. 2014) and as a possibility for young students to confront thermodynamic phenomena from their everyday experiences (Haglund et al. 2016b). Our investigations have unveiled salient engagement attributes of student interaction with thermal cameras while performing simple laboratory activities. From a meaning-making perspective, a compelling characteristic of using IR camera technology is that it provides rich opportunities for pupils to combine visual, tactile and gestural experiences while they explore thermal phenomena. Furthermore, manifestation of these sensory perceptions while students express themselves through language in talking and reasoning about their experiences provides a further layer upon which to unpack the conceptualisation of abstract ideas such as heat (Lemke 1990). Furthermore, encouraging collaborative exploration in nontraditional classroom settings such as science centres can provide a multidimensional context (Falk and Storksdieck 2005) to investigate the interplay between language and interactive thermal visualisation in studying young peoples' notions of heat.

Aim of the Study

The objective of this study was to observe how young pupils interacted with IR cameras within inquiry-orientated collaborative activities around thermal phenomena at a digital science centre. As part of the observations, the specific aim was to discover what heat-related metaphors pupils expressed and used during a spontaneous exploration of the thermal properties of the surroundings and a thermos modelling exercise.

Methods

Participants, Context and Activities

The study involved eight groups (three to four pupils per group) of fourth grade children's visits to a digital science centre in Sweden. The pedagogical arm of the centre is designed with the intention to promote a creative problem-solving space and intuitive out-of-school learning experiences. Signed informed consent to participate in the visits for educational research purposes was collected from all the pupils' parents. Each group visited the centre on one occasion and participated in a

thermal workshop. The 1-h workshop comprised of an introduction (about 10 min duration) by author AL, where the infrared camera technology was introduced in parallel with a projection of the real-time visualised thermal output on a large screen. An animated simple heat-flow model was also introduced to represent heat transfer from a warm object in thermal contact with a cold object (Haglund et al. 2016b). Care was taken to explain heat transfer in literal terms with as little meta-phorical content as possible, to avoid leading pupils into a particular way of concep-tualising heat. Following the introduction, each group was provided with either a *FLIR C2* or *E4* thermal camera and asked to engage in a spontaneous exploration of the thermal properties of the surroundings (about 15 min). No specific instructions were given other than requesting pupils to explore what they desired with the infra-red camera and that they try to express their interpretations and experiences aloud as often as possible. This was followed by a thermos building exercise (about 25 min), where pupils used provided materials (e.g. paper cups, wooden skewers, water contained at approx. 70 °C) to construct a thermos. Pupils were told that their task was to insulate the water poured into a paper cup as efficiently as possible. Pupils were asked to use the thermal camera to aid their development and measure-ment of thermos efficiency while observing any heat transfer processes. Pupils were also encouraged to use the snapshot facility of the cameras to take static thermal pictures (e.g. Figs. 1, 2 and 3) as they conducted the tasks. A closing session (about 10 min) facilitated by AL involved reflecting upon aspects emerging from the work-shop and an opportunity for pupils to ask any questions they had.

Data Collection

Researcher-as-participant observations (e.g. Keys 1995) were conducted using video recording as well as additional field notes during the thermal workshop. Two oppositely positioned tripod-mounted video cameras recorded the introductory and closing sessions. In addition, each of the three researchers was equipped with a hand-held video camera, and at least one researcher followed and observed each group during their interaction with the thermal camera in the exploration and ther-mos building tasks. Apart from observing the tasks unfold, the researchers encour-aged pupils to continue pursuing emergent lines of dialogue that were relevant to the research aim by asking questions but never directed pupils' choices, hypotheses and strategies during the tasks. Furthermore, the researchers sometimes redirected pupils' attention when group focus shifted too far from the immediate task at hand. Overall, data gathering adopted a quasi-ethnographic approach (Murtagh 2007) that concentrated on listening to the dialogue and exchanges and watching the behav-iours that ensued when pupils performed the tasks with, and around, the IR cameras. In this regard, the field was the digital science centre, and the researchers engaged in a reciprocal observation and interpretation of pupil visits. Immediately following each visit, at least two (and often all three) of the researchers discussed each other's observations and either audio-recorded these reflections or penned notes that were used to help inform the data analysis.

Data Analysis

As part of the interpretive research design, video recordings were viewed for evidence of expression and variation of metaphoric relations in pupils' dialogue and behaviour while they engaged an infrared camera in experiences and discussions about thermal phenomena. In this regard, rich exchanges, where conceptualisation of heat in terms of colour, movement and change, were identified as critical events that represented the empirical content of the study (e.g. Derry et al. 2010). Subsequently, the current work focuses on a qualitative metaphor analysis (e.g. Moser 2000) of six selected events that unfolded while two different groups of pupils performed the tasks. The selection was based on exchanges rich in metaphorical dialogue related to the display of the IR camera and the corresponding phenomenon observed.

The selected videorecorded events were transcribed verbatim in Swedish and translated into English. The video clips, corresponding transcripts including gestural and physical behaviours, thermal images captured by the pupils and researcher field notes comprised the data analysed in the study. The metaphor analysis proceeded in three overall steps. The first step consisted of *discovering metaphoric relations* in pupils' utterances (e.g. Grady and Johnson 1997; Lakoff and Johnson 1999). Here, attention was given to pupil expressions related to spatial relations, colour, movement and change. Secondly, identified metaphoric relations were designated a superscript numeral and paired to a corresponding metaphor or metonym and notated with capitalisation (e.g. Kövesces 2013; Lakoff and Johnson 1980). Thirdly, the emergent pairings are discussed in the context of the event to reveal pupils' use of metaphoric relations in their expression and conceptualisation of heat-related phenomena.

Results and Discussion

The results of this study are presented as six events that transpired in two different pupil groups while they participated in the thermal workshops. The first four events capture one of the group's interactions during the thermos modelling task. The last two events concern another group's spontaneous exploration of the thermal properties of the surroundings. Each event is presented by first describing the interaction taking place, together with corresponding transcript dialogue, and, in some cases, videographic and thermal imagery associated with the exchange. This is then followed by identifying and analysing the metaphors that pupils expressed and used in their interpretation and experiences of thermal phenomena.

Heat Wants to Move

During this event, AL is halfway through the introduction phase. The following excerpt from the discussion took place in front of an interactive whiteboard where the pupils were about to view an animation of a simple heat-flow model that represented objects at higher and lower temperature as red and blue rectangles, respectively (cf. Haglund et al. 2016b). Prior to the event, AL had introduced the thermal camera, by projecting heat visualisation on the interactive board, where both colour and temperature scales are present. At this point, AL deliberately avoids using metaphoric relations, based on movement or colour. Consider the following exchange that occurs ("P" followed by respective numeral designates different pupil participants):

> AL: And now let's see what happens if you manage to bring a hot and a cold object next to each other. You know, if you have something hot here [hand gesture] and something cold there [hand gesture], what happens when you put them together?
> P1: It gets… maybe *it wants*[2,3] to get *yellow*[1] or it will get *slightly warm*[1] in the middle.
> AL: It will become *slightly warm*[1] in the middle. Does it happen right away?
> P1: Maybe it *starts*[2,3] in one place and *spreads*[2,3] slowly. (Video camera 1, 09:00-09:45)

1. Slightly Warm for Yellow
2. Change in Heat/Temperature[2] Is Self-Propelled Motion
3. Change Is Motion

The excerpt indicates that P1 structures her utterances based on two different notions where heat is related to colour (1) and change in temperature is related to movement (2,3). In this case P1 uses "colour" interchangeably with her notion of heat; hence "yellow" is interpreted as a metonym. Therefore, P1 is able to communicate that a change in colour corresponds with her previous sensorimotor experiences of heat and also correlates with changes in temperature to changes in colour.

In this event, a necessary condition for her to conceptualise heat in terms of movement is to regard heat as a bounded entity. In order to understand physical phenomena in terms of motion, P1 divides her experience into discrete parts with which she categorises and quantifies different aspects of heat (cf. Lakoff and Johnson 1980). Doing so indicates that she utilises at least two different ontological metaphors: *Colour is a Container* and *Heat is a Container*. By utilising colour as a metonym for heat, she is also able to correlate changes in colour with changes in temperature. Also, the use of words such as "wants to move" indicates that there is a source related to heat transfer. As a result, she is able to communicate that the "colour" of heat changes according to her experiences of sensing hot and cold objects, where a change in colour covaries with the sensation of heat.

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[2] Both heat and temperature are stated as the target domain in this metaphor since it was not evident that the pupils distinguished between heat and temperature as two separate ontologies (see Wiser and Amin 2001).

Keeping the Cold Outside

In this event, KS observes three pupils during the beginning stages of the thermos modelling task. The following exchange captures a situation where the pupils start discussing thermal phenomena in relation to their thermos design, and KS commences the exchange with a question:

> KS: How will you keep the water warm?
> P2: We *close out*[1] the cold.
> P4: If we use many layers.
> P2: We will *keep*[2] the cold *outside*[1] and *keep*[2] the warm *inside*[1].
> P4: If we do a dual layer here [indicating the use of a second paper cup for insulating purposes]. Then it's *harder*[2] for the heat to *escape*[3,4]. (Video camera 1, 22:35-23:00)

1. STATES ARE LOCATIONS∗
2. CAUSES ARE SELF-PROPELLED PHYSICAL FORCES∗
3. CHANGE IS MOTION∗
4. HEAT TRANSFER IS ESCAPE

Consideration of the exchange reveals that P2 and P4 use metaphors in line with the notion of primary metaphors as derived from Grady (1997), hereafter depicted with an asterisk (∗). In this regard, P2 correlates heat with being in different states, while P4 uses terms related to motion (changes of location) as well as terms related to the degree of physical force needed to initiate movement. The utterances "inside" and "outside" are suggested to be terms used in relation to the cup as a whole and hence possibly function as metonyms during the current event. The paired metaphor relationship *States are Locations* is based on previous experiences of being within a certain bounded region in space while correlating that experience to a state (e.g. being warm, stressed or angry) (Grady 1997; Lakoff and Johnson 1999). In order to achieve metaphorical congruence, P2 utilises the ontological metaphor *Heat is a Substance Within a Container*. In this way, he is able to separate the "hot" from the "cold" by placing the "heat substance" into two separate "containers" that can be kept either inside or outside the cup (cf. Brookes and Etkina 2015). In the last turn of the exchange, P4 introduces movement into the group's collaborative reasoning. Here, P4 uses the human activity of "escaping" as a personification of a non-human heat transfer process. This provides the pupils with a specific way of thinking about heat transfer (Lakoff and Johnson 1980). The pupil's reasoning appears to be based on moving the container in which the heat is confined, where a *Change in Temperature/Heat is a Change in State* where the *Cause is (Hard) Work*.

As a whole, the event demonstrates how P2 and P4 combine metaphoric relations based on substance, movement and physical force to form a novel conceptual metaphor related to thermal processes.

Liquid Heat

Following the event above, AL and the same group of pupils engage in a further dialogue about the group's design of their thermos. As shown in the following excerpt, AL repeats what the pupils have agreed upon so far, with the aim to encourage the pupils to elaborate on their thermos design:

> AL: Ok! So, you want to have a lot of *water*[1] in the thermos and then *double layers*[2] to...
> P2: …to keep the *heat inside*[2,3].
> P4: So, it won't *leak*[2,3]. (Video camera 1, 27:15-27:25)

1. *States are Locations*/States for Location*
2. *Heat for Water*
3. *Heat is Liquid Inside a Container*

At this stage of the task, the group is working with an actual substance (water). This provides an opportunity for an expanded interpretation where states are used as: (i) a metaphor for location and/or (ii) as a metonym for locations (Kövesces 2013). Pursuing this line of reasoning reveals a situation where P2 and P4 use the metonym *Heat For Hot Water*, which might make it possible for them to conceptualise the loss of heat as water leaking out of the thermos. However, even though *Heat and Water* share a possible metonymic relationship, the ontological metaphor *Heat is a Container* is still present and provides pupils with a resource to reason about thermal phenomena such as insulation (Lakoff and Johnson 1980).

Multitude of Metaphors

As the thermos modelling task progresses, the same group of pupils proceed to compare the efficiency of two thermos designs side by side (Fig. 1, left). They have poured an equal amount of warm water into both thermoses and wait a few minutes before measuring the temperature of the container wall. Following this, the following exchange features the group becoming engaged in observing thermal processes using the IR camera (Fig. 1, right) and also grasping the cup with their hands:

> P3: That one [insulated thermos] *increases*[1].
> P4: Almost one minute has passed.
> P3: Like we did […] did with the colour […] colours.
> P2: You will have to hold it!
> P4: It's beginning to get a bit *whiter*[2] at the bottom.
> P3: This one [insulated thermos] is *redder*[2] […] it's rising.
> P4: I think it's the steam […] It's because *the air is cold*[4] and it will <u>*come down*</u>[3,4] in the cup that will […] I guess, so it will become *colder*[2,3] […] there's not that *much red*[2,3] left anymore. (Video camera 1, 32:25-33:05)

1. *A Change in Temperature is a Change in Colour*
2. *States are Locations, A Change in State is a Change in Colour*
3. *Change is Motion*
4. Causes are Self-Propelled Physical Forces*

At this stage in the task, the pupils attend to the outside surface of the respective thermoses. As a consequence, the outside temperature is placed in a possible metonymic relationship with the temperature of the water being inside.

While discussing their observations, the pupils change the source element of the expressed metaphorical relationship from colour to movement. At this point, the pupils appear to have access to a richer metaphorical language and are therefore able to relate thermal phenomena to experiences of both colour and movement. This is so even when some of the metaphors are being manifested in non-scientific ways (cf. section "Multitude of metaphors"). In this regard, the pupils gradually shift the way in which they conceptualise heat variation, from being based on a simple and rather discrete *Change in States* metaphor (similar to a temperature scale) to the more complex metaphor *Force-Dependent Change in State* motion metaphor, where the quality of the force corresponds to the nature of the change. While both metaphors are related to movement in physical space, the latter bears potential for more qualitative descriptions of thermal phenomena.

Sensory Heat Traces

In an event featuring another group, three pupils explore the thermal properties of the surroundings. Following a preceding experience that occurred during the same task, P1 proposes setting up a second experience contained in the current exchange. As shown below and visually in Fig. 2 (left), P1 and P2 perform the following experiment, while P3 observes the process using the IR camera (Fig. 2, right):

> P1: Let's put our hands on the table!
> P2: Why?
> P1: That's when you see the heat traces [both P1 and P2 *start rubbing their hands*[1] on the table].
> P3: It's getting *more and more yellow*[2].
> KS: Wow! Check it out!
> P1: Great! This is good! (Video camera 2, 00:51-01:03)

1. *Cause is Physical Force*
2. *Heat is Colour or Colour For Heat*

Based on the above excerpt, it is evident that P1 has a clear intent in proposing the spontaneous activity, and the group uses the camera to confirm their hypothesis. In this event, the metaphors that emerge are expressed in bodily behaviours rather than in direct language. In this case, colour serves at least one function during the group's reasoning – a metaphorical relation to the experience of heat.

When rubbing their hands against the table surface (Fig. 2), P1 and P2 are able to experience friction heat being generated while applying physical force against the table. In this manner, these actions provide a pathway for transforming the *Colour for Heat* metonym into the *Heat is Colour* metaphor. Hence, by integrating a sensory experience into the activity, the pupils gain access to a sensory domain that makes it possible to form a conceptual metaphor for heat (Grady 2005).

Conflicting Sensory Experiences

As part of continuing with the spontaneous exploration activity, the same group of pupils decide to use the thermal camera to explore the temperatures of different objects and surfaces. The following excerpt captures the exchanges between KS and the pupils in determining which of three surfaces are at the lowest temperature – a part of the wall that is painted with magnetic paint, the floor surface and a metal postbox.

> P1: It [colours on the camera display] is somewhere *in between*[1]!
> P3: It [colours on the camera display] is like *yellow*[1].
> P1: Green […] A bit *yellow*[1] at the edge [of the post-box].
> KS: So, what do you say? What surface is *colder*[1]?
> P1: I think this [the floor] is *colder*[1]
> P3: No, this [the wall painted with magnetic colour] is *warmer*[1]
> P1: No, look here [points to the IR camera display]. This [the floor] is *green*[1]. This [metal post-box] is *yellow-orange*[1]. So, this is *warmer*[2] [touches the post-box and appears confused].
> KS: Really?
> P1: I think so. Look! [shows the display to R2]. This is *green*[1]. This is […] a bit […]
> KS: *Green*[1]?
> P3: But I held my hand [felt the surface].
> P1: Yes but take it [the hand] away! But it's kind of […] it [the post-box] is *cold*[1] and *warm*[1] […] in between […] well, I don't know.
> KS: Well, look again…
> P1: …but it's *warmer*[1] now … [looks at the camera] hmm […] no, I don't know […] somewhere *in between*[1]. (Video camera 1, 13:30-14:48)

1. *Colour for Temperature/Heat*
2. *Colour for Sensory Experience*

Throughout the event, it is evident that colour is used as a metonym for temperature. As the pupils are referring to the display on the camera, there are no sensory elements related to heat present in the dialogue, and hence no metaphoric relations are possible (Grady 2005). However, at one point during the exchange, P1 and P3 begin to question the correspondence between colour and temperature. This occurs at the same time as when the pupils begin touching the objects under discussion (the wall and the metal postbox). This situation, where expected sensory experiences do not match the pupils' nonsensory information (the visual representation of heat), seems to confuse the pupils to the extent that they appear no longer to trust the information displayed on the camera apparatus (cf. Lewis and Linn 1994).

As described earlier, due to inherent thermal properties of different materials, objects with otherwise identical temperatures can be associated with different human sensory experiences that shape "common-sense" conceptualisations of heat, where understanding temperature is correlated to what feels "hot" or "cold". Taking this into consideration, it is plausible that the cognitive conflict that the pupils experience is a result of a situation where their common-sense theory of heat starts to break down. With the camera at hand, it is no longer possible for the pupils to correlate their bodily sensory experiences to colour or to temperature. At this point in the activity, the pupils have lost access to any heat metaphors and are unable to reach any conclusions.

Conclusions and Implications

The objective of this study was to observe how young pupils interacted with IR cameras within inquiry-orientated collaborative tasks and to discover what metaphors pupils expressed and engaged during a spontaneous exploration of the thermal properties of the surroundings and a thermos building modelling exercise. Findings show that the pupils often created their own unique collaborative learning scenarios using the IR camera as a measuring device (e.g. Figure 1). In addition, pupils often engaged in experiences where they used their hands to transfer heat to objects (e.g. Figure 2) or placed their bodies in contact with surfaces (e.g. Figure 3, left) to transfer "heat angel" thermal signatures onto insulating materials (e.g. Figure 3, right). In this regard, the IR cameras served as a communicative resource allowing the pupils to evaluate, and when needed, redesign their investigative work according to their prior and emerging hypotheses.

The study indicates that the pupils almost exclusively conceptualised "heat" as a noun. This was manifested in expressions such as "keep the heat inside", "harder for the heat to escape" and "it wants to get yellow" The two latter examples also show that the children tend to personify "heat", thus extending the ontological metaphors in such a way that the metaphoric relations are brought even closer to their own experiences of the "real" world (Lakoff and Johnson 1980). The above metaphors used by the pupils correlate with their sensory experiences of heat, where an object is considered as being in different states of "hotness" (Wiser and Amin 2001). Altogether, this allows for the formation of a fully embodied metaphor for heat and, hence, an everyday conceptualisation of heat (Lakoff and Johnson 1999; Grady 2005). All three of these utterances are examples of where the conceptualisation of heat in terms of movement requires a "mental" object to be moved (Johnson 2007). However, this ontology of heat is very different from the scientifically accepted ontology of heat: energy transfer/exchange is considered being a consequence of temperature differences (Romer 2001; Wiser and Amin 2001). By utilising the ontological *Substance* and *Entity* metaphors, the pupils were able to "fill in the blanks" and form coherent metaphors for "heat".

The study also reveals that the pupils used colour as both a metonym and a metaphor for heat and/or temperature. This was seemingly dependent on how the pupils related their ontological metaphors (e.g. *Heat is a Container, Heat is a Substance*) to sensory experiences of motion. In cases where pupils conceptualised "heat" as a nonmoving entity, "colour" was used as a metonym for heat (Lakoff and Johnson 1980; Kövesces 2013). In cases where the pupils conceptualised "heat" as a moving and/or metaphoric entity (*Container, Substance* or *Liquid*), "heat" and "colour" were used as conceptual metaphors for heat. The use of conceptual metaphors related to colour also implies that the visual representations of heat serve as an extension of already existing metaphoric expressions of heat. Albeit so, since the pupils conceptualise heat in terms of colour and movement, colour is also conceptualised in terms of movement. This is manifested in expressions such as "it [the yellow] starts in one place and spreads" and "it [the less red] will come down".

These are examples of where heat is being conceptualised as a *property* of an object rather than as a noun. As a consequence, it becomes possible for pupils to reason about thermal phenomena without having to utilise the above-mentioned metaphors. It follows, in principle, that by using colour as a metaphor for heat, it is plausible for pupils to conceptualise all aspects of heat within the boundaries set by our sensory experiences of movement (Johnson 2007). The presented results show that movement is a central constituent for conceptualising heat, which implies that spatial cognition plays a crucial role in learning about heat phenomena (Grady 2005; Gallese and Lakoff 2005).

In conclusion, this study demonstrates that access to different metaphoric relations is important as both a resource for communication and for reasoning about abstract phenomena. Pupils' conceptualisation of heat (*Heat is an Entity and Heat is Colour*) is highly related to the experience of movement, indicating that spatial cognition is central to the conceptualisation of heat. Furthermore, the study indicates various shifts in pupils' conceptualisation of heat, which demonstrates the importance of using multiple metaphors in exploratory learning situations. Future studies will focus on how, and in which experiences, novel conceptual metaphors are formed, and how these experiences can be exploited as a resource for expanding already existing metaphoric relations present in the classroom. A core feature of the work will be to analyse how pupils' use of conceptual metaphors relates to the blending of primary metaphors within learning situations (e.g. Grady 2005; Lakoff and Johnson 1999).

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Science or Magic? Reactions of 5-Year-Old Pupils to a Counterintuitive Experiment

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Introduction

Since Roger Bacon at least, the effective test of the reproducibility of a physical phenomenon is considered a good scientific practice (Bacon 1267), and the inability to reproduce an experiment a signature of a methodological deficiency. Nevertheless, testing the reproducibility of an experiment still appears today as an issue for professional research (Nature 2016; McNutt 2014). For example, the French CNRS (National Center for Scientific Research) has recently published a guide to promote responsibility and integrity in research, in which they emphasized the necessity for researchers to ensure the transparency of the operations to allow the reproducibility of their experiments (CNRS 2014) in physical sciences as well as in fields where the concept of reproducibility may appear less simple such as biology or social sciences (Zwaan et al. 2017).

This issue also appears, although implicitly, in the Next Generation Science Standards under the label "Planning and Carrying Out Investigations" (Appendix F, NGSS Lead States 2013). The NGSS recommends that the number of trials has to be considered as early as grades 3–5; that grade 6–8 students have to reflect on "how measurements will be recorded and how many data are needed to support a claim"; and that grade 9–12 students have to reflect on the "accuracy of data needed to produce reliable measurements." The important issue of the interpretation of the data, namely, that "all scientists performing the same procedures may not get the same results" (Lederman et al. 2014), thus appears irrelevant at Kindergarten level. The French national curriculum for Kindergarten (2- to 5-year-old pupils), elementary

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school (6- to 11-year-old children), and middle school (12- to 15-year-old students) asks teachers to practice scientific inquiry but doesn't introduce reproducibility at all: it is asked that pupils (1) identify scientific questions, (2) propose one or many hypotheses to answer to the question, (3) conceive an experiment to test them, (4) measure directly or indirectly physical quantities, (5) interpret experimental results to conclude and communicate them with argumentation, and (6) develop simple models to explain observed facts and implement approaches which are specific to sciences (Journal Officiel 2015). At high school level, although students have to deal with errors and uncertainty of measurements and have to learn how to express a numerical result in an acceptable way (e.g., relative precision), the link with the reproducibility of an experiment is never explicitly done.

While one could be tempted to consider the mention of reproducibility in the curriculum as useless, through the assumption that Science teachers themselves have fully integrated the test of the reproducibility of an experiment as a core practice, a recent French study shows that it is not always the case. When a multiple-choice questionnaire was proposed to them, only 36% of French Physics teachers who participated to a massive study from the French Institute of Education affirmed that for an experiment to be scientific implies that it is repeated many times (IFE 2011; 2376 participants). A previous study performed with French Kindergarten and elementary school teachers revealed a similar difficulty: only 12% of them cited the verification of the reproducibility of an experiment as a means to distinguish a scientific experiment from a nonscientific one (Blanquet 2014).

Regarding pupils, Schauble (1996) and Varelas (1997) highlight that elementary school pupils have difficulties to "conceptualize the procedure of repeating trials and finding the best representative of the results of these trials" when these trials yield to different measurements. According to Varelas:

> *some children seemed either not to have constructed an idealization which would allow them to reason that repeating exactly the same experimental situation would yield exactly the same result, or unwilling or unable to coordinate that idealization with their empirical knowledge that repeated trials do not actually produce exactly the same results.* (1997, p. 866)

Metz (2004) asked second and fourth–fifth grade pupils how to reduce the uncertainty of the results of their own experiments and brought out, among other results, that one strategy used by 5% of these second graders and 58% of these fourth–fifth graders was to replicate the experiment.

Studies involving Kindergarten children and explicitly proposing them to express their point of view regarding the reproducibility of an experiment nevertheless remain scarce. In a previous study, we showed that the notion of reproducibility appears accessible to 5-year-old children who were interviewed on an experiment they had done at school (Blanquet 2014; Blanquet and Picholle 2015). This article aims to explore the ability of 5-year-old pupils to consider an experiment as reproducible, independently of what has been done inside the classroom with their teacher before.

As dealing with quantitative experiments appears challenging for young children, we decided to use a qualitative experiment, for which it is easy to observe that repeating the same experimental situation will yield the same result, even if small variations of the parameters of the experiment occur (under the condition that the

chosen experiment is robust enough). For instance, an object either sinks or floats, falls or not, water either freezes or not, etc.

The use of a qualitative experiment allows to separate the understanding of repeating an experiment from dealing with the dispersion of measures, which is the focus of numerous studies. One difficulty of this approach consists in the fact that a child might consider as obvious the reproducibility of phenomena well-known to him, or even of a phenomenon he merely has already seen. To avoid this obstacle, we decided to use a counterintuitive phenomenon.

Such a choice offers another advantage as a nonscientific approach would be to consider a seemingly counterintuitive phenomenon as magical. Believing in magic and in wizardry implies to attribute to some individuals with a special gift the ability to produce phenomena which non-gifted persons cannot reproduce. From this point of view, magic is diametrically opposite to scientific methodology, which claims the possibility for anyone to reproduce a phenomenon as a root of experimental science. Such claims are not unusual, as established by a 16-year-long project of the University of Nice, France. Henri Broch, a physicist; Gérard Majax, an illusionist; and Jacques Theodor, a physicist and sponsor, proposed a challenge with a $250.000 prize to anyone who would have been able to demonstrate the existence of a paranormal phenomenon under duly controlled experimental conditions. The challenge was stopped after 16 years of unsuccessful tests by the team, the prize remaining unclaimed (Charpak and Broch 2003). While ostensibly obsolete in modern societies, such magical thinking remains strong enough for many counterintuitive experiments to generate a sensation of strangeness.

It is the case of the manipulation which consists in filling with water a can in which a visible hole has been pierced and stopping the water from flowing through the hole by closing another small non-visible hole with a finger (Novellaux 2012), which is counterintuitive enough for some "magicians" to use it in their shows.

We assumed that such an experiment would also appear surprising for 5-year-old children. It thus provides a good situation for identifying the reactions of pupils, their ability to consider such an experiment as reproducible, and their perception of magic.

Are 5-year-old children able to consider a counterintuitive experiment as "science" and to consider its reproducibility? Do they consider this experiment as magic? In both cases, are they able to justify their position? How do they consider the necessity of testing the reproducibility of an experiment?

Method

Participants

The study involved 62 5- to 6-year-old children from 4 classes, belonging to two different schools from Bordeaux, in France. These schools were chosen as fairly average in France with respect to socioeconomic context. The four teachers ranged from 45 to 54 years old and had a strong experience as Kindergarten teachers (between 12 and 20 years). None of them had a scientific background, and during

the last 10 years, none of them have received a continuing training in science teaching. During the scholar year, they had studied with their pupils the human body, worked on the five senses, have planted grains, and constructed a technical object, and some of them have visited a farm or had an animal inside the classroom. All these activities are included in the French Kindergarten curriculum. The pupils were taught science between 0.5 and 2 h per week. All the children were interviewed in June, at the end of the school year.

Data Collection

The students were presented with a capless bottle in which a hole had been pierced. They were first asked if it was possible to stop the water from flowing through the hole without closing it with a finger. They were then shown that this result can be obtained by screwing the bottle's cap. They were explained that this happens because air can no longer enter the bottle and thus no water can leave it, when the cap is closed. Individual interviews were realized by the children's own teachers in a quiet place. All of them used the same questions and followed the proposed order to interview the children (Table 1). A specific guideline was provided to the teacher to describe and explain the conditions required for the interview. The duration of the interviews was between 8 and 15 min. The interviews recordings were done by audio and transcribed for analysis.

A pilot study identified the main difficulties encountered by 5–6-year-old children when dealing with the notion of reproducibility (Blanquet 2014) and allowed to devise relevant questionnaire. Before implementation, the questionnaire was submitted to the teachers for assuring its understanding by the children (Lederman et al. 2014). The teachers validated its formulation after minor modifications and were able to identify the purpose of the questions in terms of assessment of children's understanding of the notion of reproducibility. The questionnaire involved 10 questions investigating the understanding of the notion of reproducibility and the importance of testing reproducibility both by the child himself and by others, and the pupils were systematically asked to justify their answers. Question 6 relative to the possibility that the experiment may have a magical character was the only one to require an elucidation for teachers. The teachers were then interested in the answers the children may provide to this question.

Question 6 aimed to evaluate in which measure children make the distinction about a magical and a physical phenomenon. The realization of a magical phenomenon is presumed to require specific magical skills while a physical phenomenon is presumed to be reproducible by anybody: do children presumed the same, and do children have a clear notion of this essential distinction between both types of phenomenon?

Previous studies (Blanquet 2014) motivated us to distinguish between the test of the replicability of a phenomenon by oneself and the reproducibility by someone else, somewhere else, and also from in a situation which involved the use of an argument of authority by a presumedly more experienced person.

Table 1 Questions asked to the children by their teacher

English translated questions	Original French questions
1/Do you think it would work if you did it yourself (instead of the teacher showing the experiment)?	*Est-ce que tu crois que ça marcherait si c'était toi qui le faisais?*
2/What could we do to know?	*Comment pourrait-on faire pour savoir?*
3/Was it important that you also tried out?	*Est-ce que c'était important que tu essaies aussi?*
4/According to you, if I fill again the bottle with water and if you screw the bottle's cap again, will the water also stop again from flowing?	*A ton avis, si je remplis de nouveau la bouteille d'eau et si tu recommences à visser le bouchon, est-ce que l'eau va encore s'arrêter de couler?*
5/If a 9- or 10-year-old child tells you it is not possible, what would you answer to him?	*Si un grand de CE2 te dit que ce n'est pas possible, qu'est-ce que tu lui réponds/dis?*
6/If someone tells you that it is magic, what would you answer to him?	*Si quelqu'un te dit que c'est de la magie, qu'est-ce que tu lui réponds/dis?*
7/Do you think that it would work if a younger child (3 years old) was trying?	*Est-ce que tu crois que ça marcherait/peut marcher si c'était un enfant plus petit/de PS/de MS qui essayait?*
8/Is it important that other children try out?	*Est-ce que c'est important que d'autres enfants essaient?*
9/A child tells you that it works only because it is you. He tells you that if he tries himself, it will not work. What do you answer to him?	*Un enfant te dit que ça marche seulement/uniquement parce que c'est toi qui le fait. Il te dit que si lui le fait, ça ne marchera pas. Qu'est-ce que tu lui réponds/dis?*
10/Do you think that it could work if your mother was doing it at home?	*Est-ce que tu crois que ça marcherait/peut marcher aussi si ta maman le faisait à la maison?*
11/Is it important to try out not only at school but also at home?	*Est-ce que c'est important d'essayer aussi dans ta maison et pas seulement à l'école?*

Results

The children answered all the questions and justified an average of 6 of their answers (22 children provided justifications to more than 8 answers and 10 to less than 3).

A Diversity of Justifications

Question 1

More than 2/3 of the children considered that the water would stop from flowing if they screwed the bottle's cap themselves, instead of the teacher (42/62, 68%), 14 children didn't know, and 6 thought that the water would not stop from flowing.

Nineteen children (31%) proposed a justification:

- Among them, one child used the provided explanation: "I have understood that the air enters through the big hole."

- Eleven children expressed in some way that an experiment should be reproducible to justify their answer. Five of them explained that if it had worked for the teacher, it would work for anybody (e.g., "you did it and it's going to work for everybody," "if it works with you, it can work with anybody") or just stated that it would work for anybody (e.g., "because everybody can succeed"). Two children explained that if they did the same thing, they would get the same result (e.g., "because if I did the same, it will work too"). Three of them assumed (e.g., "you did it, it can also work for me"), and one expected by induction that the result would be the same for them as for the teacher ("If it works for you, it has maybe to work for me").
- One child spontaneously used the word "magic" to justify: "because I always do magic at home."
- Six children proposed justification fully unrelated to reproducibility (e.g., "because I'm 5 years old").

Question 2

Question 2 was not directly related to the reproducibility. Twenty-five children proposed to try out (40%), and one child expressed his surprise: "It works, it is Magic!"

Question 3

Forty-five children (73%) consider it important to try out, ten don't know, and seven didn't think that it was important for them to try out. Thirty-two of the children (52%) provided a justification. Only four of these justifications came from children who considered that it wasn't important to try out: three of them are not related to reproducibility (e.g., "because it takes too much time," "because I wanted to do it"), and one refines his mind: "it is important only if someone has lied or something like that."

Among the 28 other justifications:

- One child who had taken the initiative to try out without waiting for the teacher to ask the question explained that it was important "because I wanted to see if you were a wizard or not."
- Three children who didn't know if the experiment was reproducible, or who thought that it wasn't, explained that it allows to know the answer (e.g., "If I hadn't tried out, I would not have known if it worked," "because if you don't try out, you cannot know the answer").
- Four justifications come from children who justified their answer to the question 1 by using the reproducibility of an experiment. Two of them explained that it was important to try out to check their idea: "We try out and then we are sure," "We have seen that it was working for me." One who thought that the experiment was reproducible by everybody noticed a parameter to be controlled to ensure it: "because, if not ([try out], you could not succeed. If you don't close well the cap,

you could have thought you had not succeeded." The last one who affirmed pre-
viously "because it is the same" explained that it was important for him to try out
"because he didn't know if he would succeed."

- Eighteen were not related to the test of reproducibility (e.g., "Because I didn't
  know how to do it," "I will be able to show to my parents and they can say it is
  good").
- Two children merely emphasized the necessity to try out: "because you always
  have to try out," "Everybody has to try out."

Question 4

Forty-seven children considered that the same thing would happen if they re-did the
experiment (76%), and 43 justified their answer (69%). Eleven justifications came
from children who *didn't* know (5) or thought that the water will not stop flowing
again (6).

- Five justified by the fact that "It is always the same."
- Six used their previous result to conclude it will work again (e.g., "because when
  I had try out, it had worked"), and among them, two use induction (e.g., "if it has
  worked the first time, it will work the second time," "As I have done it, it will
  work again and I and you did it, it makes two of us").
- Four used the explanation provided to them (e.g., "Air doesn't enter anymore and
  water doesn't flow out").
- Five explained it was linked to the cap which had to be closed (e.g., "When you
  close the cap, water doesn't flow anymore"), one being not sure of the result ("I
  think it is because you have always closed the cap").
- Seven explained their answer by introducing a new parameter: would it remain
  the same if they did it without help (1) or with two hands or with more or less
  water, one being not sure that changing the amount of water has an influence
  (e.g., "maybe if there is more water, it will flow out") and two thinking it changes
  the result (e.g., "There will be too much water and it doesn't work").
- Four were not sure of the replicability of the phenomenon ("As I have already
  done it, maybe it's going to work," "I think it will re-do the same").
- Thirteen children's justifications were out of scope (e.g., "I want to do it again,"
  "My brother said that").

Question 5

Most of the children (51/62, 82%) considered that it is possible to prevent the water
from flowing out, even if an older child says so. Sixteen children's (26%)
arguments:

- Four proposed to show the experiment, and another one proposes the older child
  to try out and explain "If it doesn't work, I tell him you have to be younger."

- Two explained the phenomenon (e.g., "because air can stop the water").
- Two used the authority of the teacher (e.g., "An adult has said it to me and he knows better than you").
- Six used the primacy of experience (e.g., "because I have already try out").
- Only one used the reproducibility's argument to answer: "because it is always the same."

Question 6

Children were divided on the answer to provide to someone who affirms that it is magic. Thirty-four children would merely respond to someone who says "it's magic" that it is not (55%); 20 would agree it is magic and 8 don't know.

Twenty-one children (34%) provided a justification; 16 justified it by stating that "it's not magic" and 5 that "it is magic."

- Seven used an explanation: five explained that the air prevented the water from flowing out, and two cases related this explanation to magic (e.g., "Air enters and water goes out, it is magic"); two provided another explanation (the cap which closes the bottle or the presence of the hole) and used it to justify that it was not magic.
- Three associated magic with a specific tool: "because there is no magic wand" (No), "my hands and a scarf make magic" (Yes), "at home, I don't have magic but I still have a magic wand to make magic" (Yes).
- Six proposed arguments relative to the supposed characteristics of a magical phenomenon to eliminate the possibility ("because it is easy to do," "because I have done it" (2), "because water doesn't disappear"), by explaining "someone has taught it to me" or that "it looks like magic but it is not." Another child, aware that the phenomenon is not magical, still precised "well, it is rather a little bit magical."

Among the 20 children who proposed a justification suggesting the idea of reproducibility in the previous questions, 6 qualified the experiment as magic, but only 1 justified this answer by the fact that "it is fun." Six out of the other 14 children justified their answer by the proposition that magic doesn't exist without some specific tool supposedly characteristics of a magical phenomenon, such as a wand.

Question 7

Forty-four children (71%) considered that a child younger than themselves can observe the same result if he followed the same procedure; seven considered that the younger child would not, and eleven didn't know. Forty children justified their answers (65%):

- Nine identified technical problems as a source of difficulty for young children (closing the cap, stabilizing the bottle).
- Three explained that a very young child (2–3 years old) would not be able to obtain the result but one of an intermediate age (3–4 years old) would.
- Four think that young children "don't know."
- Seven were out of scope (e.g., "Mom told me").
- Four explained that the observations were possible with anybody.
- Eight induced that, since the experiment was working for them or for the adults or older children, it would also work for the younger one (e.g., "because the older can do, it means the younger also can," "if it works with me, it works with younger").
- Three considered the similitude of the apparatus (e.g., "because it is the same objects").
- One explained it by the fact that the same physical process was involved: "there will be no air and after water cannot flow out."
- One made the hypothesis that "maybe it works because with us it works."

Question 8

Forty-two children (68%) think it is important that different children try out, 5 don't know, and 15 think it is not. Forty-four children (71%) provided a justification:

- Seven focused on the interest to know or to learn (e.g., "everybody has to know").
- Six considered it important to try out (e.g., "You have to try out").
- Ten would like others to be able to do the experiment (e.g., "For everybody to be able to do it").
- Two wanted to share with parents or friends (e.g., "To explain to my parents").
- Twelve were out of scope (e.g., "Mom explained to me," "Water will stop flowing out").
- Three insisted that it would depend on the other children's willingness to do the experiment (e.g., "If they like to do it").
- Three considered it important to check whether the experiment worked with other children or not (e.g., "because we don't know if they can do it or not," "because they try out and we see if they can succeed," "to see if they can do it").
- One commented that "if they try out and are afraid it is not going to work, they do it and it will work."

Question 9

Fifty children (81%) considered at this stage that the experiment didn't work for them only; ten didn't know, and two affirmed that they were the only ones but didn't justify this assertion. Thirty-eight children justified their answers:

- Fifteen explained that the child has to try out.

- Six affirmed to the child that "it works."
- Four answered out of scope (e.g., "It is not important").
- Five proposed an explanation: closing the cap is the solution (e.g., "when you close the cap, air doesn't pass anymore").
- Two who "didn't know" said that "maybe it is going to work for you, first you have to try out" or "maybe it will."
- Three affirmed it works for everybody.
- Three reintroduced magic into their answer: "it is just magic but as you can do it, all the children can do it"; "I can do it, why don't you manage to do magic?"; "If it works, it is a magic trick, if I tell him, he will believe it."

Question 10

Fifty-six children (90%) considered that, if their mother did the same experiment at home, the same thing would happen, three didn't know, and three thought that the same things would not happen. Fifty-one justified their answers (82%):

- Twenty-two answers were irrelevant (e.g., "My Mom always do it").
- Twelve focused on the fact that their mother is an adult, or just older.
- Two induced that if the experiment worked with them or the teacher, it would also work for their mother (e.g., "because you did it, it works with adults").
- Four focused on the similarity of the apparatus (e.g., "if she takes the same objects, it will work").
- Three considered that it would work with anybody.
- Three considered that if it worked at school, then it would also work at home, and one affirmed that it would work anywhere.
- Four considered that it would always work.

Question 11

Forty-one children (66%) considered it important to try out at home, 16 didn't think so, and 5 didn't know. Forty-four children (71%) justified their answers:

- Sixteen answers were irrelevant (e.g., "Because your dad also told me the same").
- Thirteen children explained that redoing it would help to remember or learn it (e.g., "because I want to get it").
- Seven children wished to share the experiment with their family (e.g., "all the family will know").
- One explained that "it is very important, very special, very magic."
- Two considered it important to try out in both places.
- Three focused on the ability to do the experiment anywhere: "we can do it everywhere," "in all the buildings we can do it, wherever we want," "we can do it wherever we want."

- Two considered it important to try out in two different places to check that it didn't change the result: "we can see it works," "to see if it works everywhere," "it is important to try out everywhere."

Synthesis Table

Table 2 synthesizes the justifications used by the children to affirm at some level the notion of reproducibility.

Children Expressing Reproducibility and Its Importance

Among the 62 children, only 26 were able to justify their answers by referring directly or indirectly to the notion of reproducibility for one question at least.

- For 12 of them (20%), the reproducibility of an experiment is mobilized three to four times.
- Nine (14%) expressed twice justifications related to reproducibility and repeated the provided explanation to justify their answer. And for five of these children, this expression appeared at the very end of the questionnaire (Q9–Q11).
- Seven children call upon reproducibility just once, and three of them expressed it as a mere possibility.
- Only one child (with five justifications based on reproducibility) expressed an interest to try out the experiment by himself in terms of checking its reproducibility ("We were able to see it was working for me").
- Only three children appeared able to consider that it was important to check whether it worked the same way with other children (Q8), and two appeared able to consider that it was important to check that it worked the same way in different places (Q11).

Discussion and Conclusion

Five-year-old children appear to be able to consider a counterintuitive experiment as reproducible. Their perception of magic doesn't seem incompatible with the possibility to reproduce an experiment themselves, and the word *magic* doesn't seem to have a strong value for them, besides being used to express that they considered doing the experiment rather fun. For one child, who spontaneously wanted to try out "because I wanted to see if you were a wizard or not" (Q3), the magical character of a phenomenon was associated with his own ability to reproduce it, but such an association doesn't appear clearly through the answers of the children to the question Q6.

Table 2 Categories of answers related to the notion of reproducibility and number of answers for each category (25 children, one child can belong to more than one category)

Type of answer	Q1	Q4	Q5	Q7	Q9	Q10	Q11	Total	%
Results of the experiment independent of the person who makes the experiment ("it works for everybody")	5			4	3	3		15	24%
Identification of similitude between what is proposed and what has been done ("because it is similar")	2	5	1					8	13%
Results of the experiment independent of the place ("it works everywhere")						3	6	9	14%
Consideration of the similitude of materials or conditions ("because it is with the same objects")				3		4		7	11%
Reference to the fact it has already been tried out and it works ("I have already tried out and it has worked")		5						5	8%
Induction from the result of its own experience to the result of other children ("If it works with me, it works with younger children")				8				8	13%
Induction from the result of the teacher to its own result ("you did it, it can also work for me")	4							4	6%
Induction from the result of the teacher to the result of other adults ("because you did it, it will work with adults")						2		2	<1%
Generalization from the fact that the result was similar for two different persons to everybody ("as I have done it and you have done it, we are two, it will work again")		1						1	<1%
Total	11	11	1	15	3	12	6	59	

In both cases (questions about reproducibility or about magic), less than half of them appear able to justify their position in a relevant way.

About 42% of them (26/62) provided an explanation integrating an element related to some level of understanding of the reproducibility of an experiment, but the independence of the result to the place (14%) or the operator (24%) is seldom evocated, such as the necessity to control the conditions or the similitude of the materials (11%). Nevertheless, some of them appear able to build explanations based on the experiment they have just witnessed. The children's understanding of the interest of testing the reproducibility appears quite poor (less than 7% of answers justifying the interest of such a test) and less important for an experiment they just discover than for a well-known experience (up to 25%, Blanquet and Picholle 2015), which corroborates previous experiments (Metz 1995).

These first results strongly suggest that it is possible to work with 5–6-year-old children on the notion of reproducibility. Moreover, the developed questionnaire based on the discovery of a new experiment appears well-understood by children. A

next step will be to identify its ability to discriminate children having specifically worked on reproducibility from other children.

In this study, no special provisions were made to ensure that the teachers explicitly insisted on the importance of reproducibility or even mentioned the term in front of the pupils. Further observations would be needed to establish whether an explicit work on the reproducibility of every experiment performed in the frame of scientific inquiry would allow more children to get a better grasp of the notion of reproducibility and of the usefulness of its test. Nevertheless, it is common knowledge among Kindergarten teachers that young children love to perform the same activity again and again. It thus seems plausible that a mere explicit emphasis on the usefulness of this practice might help pupils to learn the concept of reproducibility in scientific experiments better.

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Part II
Emerging Identities in Science Education

Using Theoretical and Methodological Triangulation to Study Motivation in the Science Classroom

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Introduction

Research on motivation in science education relies, like research on motivation across most educational disciplines, heavily on quantitative evaluations of student self-reports, most frequently using questionnaires (e.g. Potvin and Hasni 2014). Given that motivation is "an internal state that arouses, directs and sustains students' behaviour" (Koballa and Glynn 2007, p. 85), it cannot be observed directly. Rather, it must be studied through one or more other aspects that are considered to relate to motivation; the use of questionnaires is understandable. However, as Potvin and Hasni (2014) point out: "the use of questionnaires [in motivation research] is so common that it is not impossible that researchers have somehow lost sight of its limitations" (p. 111). Further, there is a growing realisation that motivation research should move beyond the limitations of the narrow focus of questionnaire-based research and consider taking its starting point in other perspectives and methodologies, including qualitative ones (e.g. Nolen et al. 2015; Potvin and Hasni 2014). One such potential starting point is the classroom. In this chapter, I posit and evaluate a theoretical model that allows us to link student motivation as traditionally measured with questionnaires, to student motivation and engagement in the science classroom as well as to students' experiences of the science education classroom. Hence, the purpose of this chapter is to evaluate a new theoretical model of motivation and to show how this new model captures contextual and situational motivation of relevance for the science classroom. Here, contextual motivation is motivation towards science in general, and situational motivation is motivation at a particular point in time, for example, during a specific science lesson.

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In classroom settings, opportunities for motivation can be seen as a dynamic process (Dörnyei and Ushioda 2011). These opportunities are provided by specific situations as well as student motivation and engagement throughout the same situation. Understanding these dynamic processes would allow us to understand how and potentially why motivation fluctuates and functions in the science classroom. It could also allow us to understand how the specific science education situation connects to student motivation for science in general. The theoretical model I propose supports motivation as a multi-level and dynamic construct. This is best investigated using a mixed-methods approach and requires that the definition of motivation is extended both to give the context a more central role and to highlight the complexity of motivation as a process in the classroom. The definition of motivation used therefore is: "an interplay between internal and external factors that stimulates peoples' energy, commitment, interest and effort to start up and continue to work towards different goals" (Hellgren 2016, p. 2).

This chapter begins by proposing and justifying a new theoretical model for motivation in the science classroom that includes the classroom as well as general motivation for science. It continues with an exploratory evaluation of the model and whether it provides new and useful insights into motivation in the science classroom. To do this I apply the model to the results of a mixed-methods study of three secondary classrooms where teachers implemented and students engaged in a novel science task as a part of a partnership with scientists' project called the Medicine Hunt.

A New Model for Motivation in the Science Classroom

The new theoretical model that I develop in this section views motivation as a multi-level and dynamic construct and captures contextual and situational motivation of relevance for the science classroom. The model combines multiple theoretical perspectives to produce a model of motivation that supports a multi-perspective view of motivation of relevance to complex classroom situations. The proposed model supports multiple methodological perspectives to study motivation in science classroom situations. In combination with self-determination theory (SDT; Deci and Ryan 1985), the model emerges from the hierarchical model of intrinsic and extrinsic motivation (HMIEM; Vallerand 2000) and the process model of motivation (Dörnyei 2000). After briefly presenting these theories, I show how they can be combined into the model I am proposing.

Self-Determination Theory

Self-determination theory (SDT; Deci and Ryan 1985) is frequently used in educational settings. SDT distinguishes intrinsic from extrinsic motivation. Intrinsic motivation is when a person acts because the value of the action is interesting, is enjoyable

or gives satisfaction, and extrinsic motivation is when a person acts to reach an extrinsic goal, for example, a grade, or to avoid punishment (Ryan and Deci 2000). Intrinsic and extrinsic motivation have different qualities. For example, intrinsic motivation has been shown to lead to high-quality learning and creativity (Ryan and Deci 2000). SDT includes a third motivation status, amotivation, which is when a person lacks motivation, exhibiting neither intrinsic nor extrinsic motivation.

Self-determination theory states that students' feelings of competence, autonomy and relatedness lead to intrinsic motivation and "high quality engagement, effective functioning, and psychological well-being" (Reeve 2012, p. 153). Thus, in SDT, students' feelings of competence, autonomy and relatedness are dependent on the specific context and can be influenced by the teacher, via teaching methods and classroom climate, or by other students. For example, students' feelings of competence can be increased by working with tasks that are challenging but not too difficult. Students' feelings of autonomy can be enhanced by student-centred teaching methods that give them freedom to influence and take responsibility for their own learning. And students' feelings of relatedness can be increased by creating settings in which they feel safe and accepted in relation to their teacher and peers and when they experience the social classroom context as open for questions and discussions. Experiencing high levels of competence, autonomy and relatedness makes a student more likely to be motivated intrinsically rather than extrinsically.

Hierarchical Model of Intrinsic and Extrinsic Motivation

Although the hierarchical model of intrinsic and extrinsic motivation (HMIEM; Vallerand 2000) is developed from Deci and Ryan's (1985) SDT, the hierarchical model includes aspects of motivational dynamics and divides the types of motivation into three levels of generality. The first and most general level, *global motivation*, captures a person's general motivational tendencies relating to their engagement in an activity and their interaction with their environment (Lavinge and Vallerand 2010). The second level, *contextual motivation*, captures a person's motivation towards engagement in a specific domain such as sports, or school subjects, for example, science. The third and most specific level, *situational motivation*, captures a person's here-and-now motivation in a specific situation.

Interaction between the different levels of generality, both in terms of top-down and bottom-up (recursive) effects, was posited by Lavinge and Vallerand (2010). They posited, for example, that if a student has high levels of intrinsic contextual motivation for science, it is likely that there is top-down effect that results in this student having a high level of situational motivation in a specific science lesson. Likewise, they posited that repeated experiences of high situational motivation in a science lesson can via bottom-up recursive effects lead to higher intrinsic contextual motivation in the school science domain for a student. Further, at each level in the model, background factors, mediated through competence, autonomy and relatedness, lead to motivation that have consequences for affect, cognition and behaviour.

Motivation as a Dynamic System

Dörnyei and other researchers in the field of second-language learning have theorised motivation as a "complex dynamic system" and explored motivation in the classroom in ways that acknowledge motivation as a dynamic and interactive process. For example, they have developed a process model to study motivation in the classroom (Dörnyei and Ottó 1998; Dörnyei 2000). It differs from the other models of motivation by adding a clear time perspective and drawing on the dynamic aspects of motivation that are inherent in complex classroom environments. They describe their approach as "a situated and process-oriented account of motivation" that "inevitably leads us to a dynamic conception of the notion of motivation that integrates the various factors related to the learner, the learning task and the learning environment into one complex system whose ultimate outcome can be seen as the regulator of learning behaviour" (Dörnyei and Ushioda 2011, p. 89). They divide the time dimension of the complex dynamic system into three stages: the pre-action, the action and the post-action stage (see Fig. 1).

The pre-action stage occurs before the actual learning situation takes place. This involves processes in which the students set their goals, form intentions and get to act. According to the model, this is affected by student's intrinsic and extrinsic motivation as well as factors such as goals, values and attitudes. The action stage is the learning situation, per se. Here, students are affected by external factors that, through feelings of competence, autonomy and relatedness, create dynamics of motivation in the classroom. A student's motivation can be stable but also change quickly in response to what is happening in the classroom. The post-action stage is retrospective and evaluating. Here, students' evaluations can be affected by, for example, their self-confidence and the feedback they receive.

A Combined Model

The new theoretical model that I posit in this chapter combines SDT with HMIEM and the process model of motivation to give a three-level structure of global, contextual and situational motivation as shown in Fig. 1.

By combining these theories, a model that allows for a multi-perspective view of motivation that includes situational motivation is created. This greater unpacking is created by the merging HMIEM with the model of motivation by Dörnyei (2000), yet the combination retains contextual information and thereby also provides information about motivation towards engagement in a specific domain.

The situational level in the proposed model is divided into three stages following the dynamic model and allows visualisation of the classroom process. In the proposed combined model, the pre-action stage overlaps with contextual motivation because setting goals, forming intentions and initiating action, is influenced by
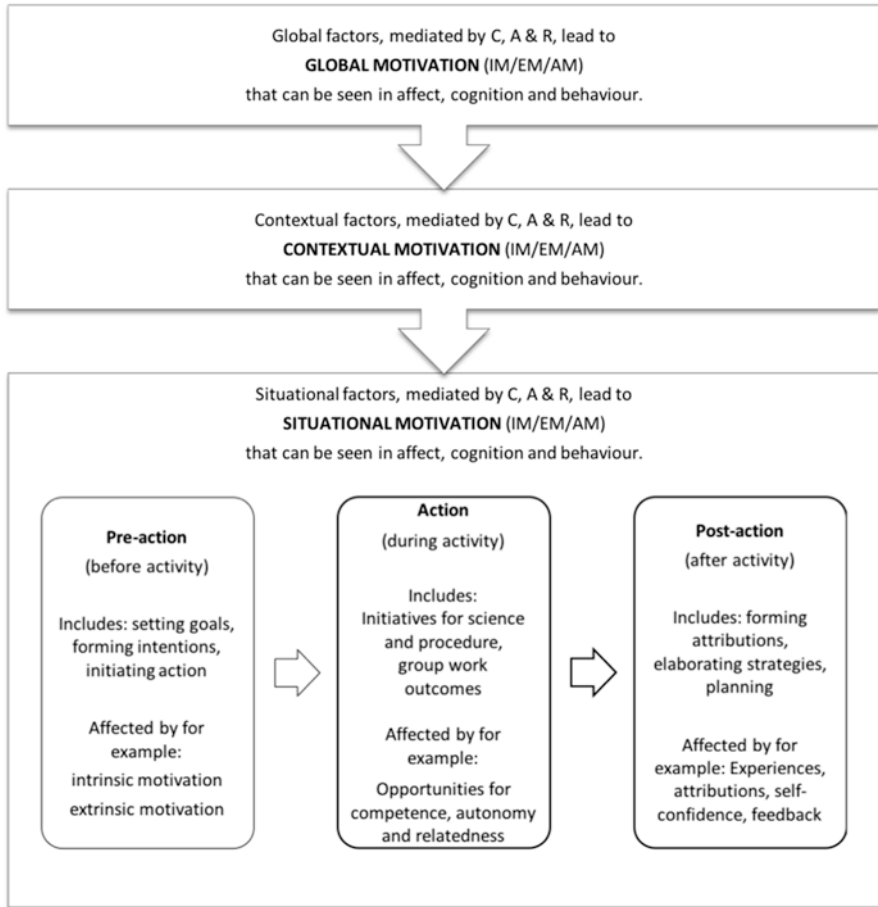
Fig. 1 Overview of the theoretical framework with the three levels of motivation: global, contextual and situational motivation. On each level, motivation is affected by factors leading to feelings of competence (C), autonomy (A) and relatedness (R). Motivation can be of three types, intrinsic (IM), extrinsic (EM) or lack of motivation, amotivation (AM). Situational motivation is divided into the pre-action, the action and the post-action stages. For each stage, examples of what is included and factors affecting them are shown. Developed from models presented by Dörnyei (2000), Vallerand (2000) and Hellgren (2016)

contextual motivation such as intrinsic and intrinsic motivation as well as goals, values and beliefs. The action stage includes the situational motivation affected by what is happening in the specific classroom, and the post-action stage refers to the motivation after the specific lesson when students reflect upon what happened in the classroom.

Testing the Model: Context and Design

In order to test the model to study motivation, data were collected from three secondary science classrooms where students participated in a partnership with scientists. This context was selected to test the proposed combined model of motivation because the partnership was designed to increase motivation for science and understanding of research through inquiry-based methods, real-world problems and introduction to how science is used by scientists. The partnership with scientists had the potential to include many factors shown to have positive links to student motivation, attitudes and interest. A recent review paper (Potvin and Hasni 2014) listed such factors and included in their list factors such as collaborative work, meaningful learning linked to daily life, hands-on and inquiry-based work, learning environments that encourage independent thinking as well as enthusiastic and encouraging teachers. Further, the context of the partnership with scientists was science classroom-based, and implemented in parallel in different schools by different teachers, and for school years where science is compulsory for all students. In sum, this specific context provided an excellent setting in which to test the proposed model.

The partnership, called the Medicine Hunt, involved 18 lower-secondary school classes and was described in detail in Hellgren (2016) and Hellgren and Lindberg (2017). The planning and implementation in each classroom were highly influenced by the school and the teacher. This provided variation in context for the different classrooms (for details, see Hellgren 2016). Therefore, the partnership provides a suitable setting to investigate the dynamic process of students' situational motivation during classroom activities in relation to their contextual motivation and a context in which to test the proposed model of motivation. The participants in the study were three secondary school teachers and 12 grade 8 students 13–14 years of age. In each class, four students with different patterns of contextual motivation for science in terms of intrinsic and extrinsic motivation were selected. This design enables us to study the dynamics of students' motivation in the different classrooms and during the authentic science task. In this chapter, the students in the three different classrooms, participating in lessons planned by three different teachers, are given pseudonyms beginning with the letters D, E and F, respectively.

Students' contextual motivation for science was measured with questionnaires, a study that is described in detail by Hellgren and Lindberg (2017). Figure 2 shows a schematic overview of how the selected students can be placed in a frame of contextual intrinsic and extrinsic motivation to visualise their replies to the questionnaire. For example, Frank is a student with high intrinsic and high extrinsic motivation for science, Dora is a student with low intrinsic and low extrinsic motivation for science and Eric is a student with high intrinsic and low extrinsic motivation for science. By using this design, students with different contextual motivation profiles are included in the study.

Fig. 2 Schematic overview of the students' contextual motivation for science in terms of intrinsic and extrinsic motivation
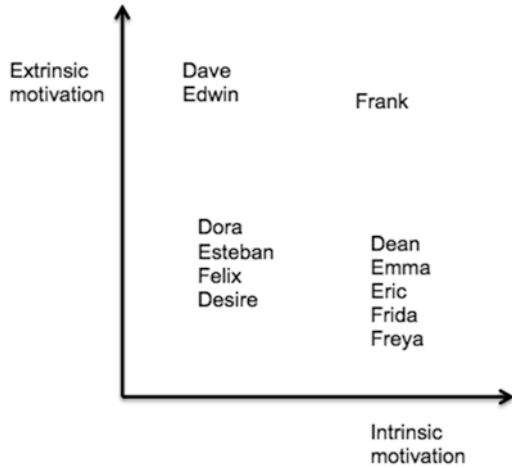
Methods

To target the different perspectives of motivation in the proposed multi-level combined model of motivation, a mixed-methods design with questionnaires, classroom observations and interviews was used. Mixed-methods methodologies have the advantage of not being limited by a particular method choice, but methods can be selected and combined based on the questions the research aims to answer. Johnson and Onwuegbuzie (2004) argue that when using mixed-methods, researchers "should collect multiple data using different strategies, approaches, and methods in such a way that the resulting mixture or combination is likely to result in complementary strengths and non-overlapping weaknesses" (p. 18). In this case, a mixed-methods design was selected to highlight student motivation in the classroom as a dynamic process by looking at it in different ways. The first way was the quantitative part contributing with students' contextual motivation for science in the design. The second was to look at students' actions in the classrooms. The third way was students' experiences of working with the task in their own words. These three ways give complementary views of student motivation and align with the elements of proposed model.

Procedure and Instruments

The students filled in questionnaires about their contextual motivation for science before starting the Medicine Hunt. For a detailed description of scales, procedure and outcomes, see Hellgren and Lindberg (2017). Based on student scores on these

scales, and their placements in intrinsic and extrinsic motivation space (see Fig. 2), the 12 participants were selected. After 5 months work with the Medicine Hunt partnership, during a lesson in which students analysed and identified bacterial colonies and reported their results to the scientists, the video observations and audio recordings took place. This was done during a researcher visit to the schools and classrooms. Before the lesson, a camera was placed in front of the classroom, overviewing activity and movement. The participating students, the teachers and the scientist were equipped with mp3 recorders. Immediately after the video-recorded lesson, the students, who were recorded during the lesson, were interviewed about their experiences of the lesson and the Medicine Hunt. Following the ethical requirements of Swedish law and the ethical guidelines of the Swedish Research Council (Hermerén et al. 2011), the guardians and the participants were informed about the study, and guardians gave written consent before the study started. Participants were told they could withdraw from the study at any time.

Factors indicating motivation in the science classroom have been studied in detail by Andersen and Nielsen (2013). They developed and tested a framework for detailed video-based analysis of motivation and interaction in the science classroom. Their framework includes students' actions and engagement, teachers' actions, questions, and responses and approach to subject matter. Andersen and Nielsen conclude that students' motivation to learn in the science classroom is influenced both by interactions in the classroom and the teachers' approach to science content. This framework and Andersen and Nielsen's (2013) conclusions influenced which teacher and student factors were considered and observed in this study. However, as their study focussed on one or two students at a time, and the study that is evaluating the proposed model of motivation focussed on a larger group of students, the choice of factors was narrower.

The observable factors selected as indicators of student motivation were students' attention during teachers' introduction, students' initiatives for participation in science, students' initiatives for participation in procedure, dynamics of group work and task completion. All factors were evaluated on relative scales, based on the work seen in the three classrooms. Student attention during teacher's introduction is defined as "students appear to be paying attention: They are not displaying any inattentive or disruptive behaviour; they are looking at the teacher and following his or her movements…" (Guilloteaux and Dörnyei 2008, p. 62), and student participation is defined as "students are actively taking part in classroom interaction or working on assigned activity" (Guilloteaux and Dörnyei 2008 p. 62).

Further, participation was divided into initiatives for science that was defined as interacting with the science artefacts and/or the group work involving the artefacts and initiatives procedure that was defined as students contributing to their group's progress in the scientific procedure. Finally, dynamics of group work was defined as to what extent the group progressed towards the goals, and task completion was

defined as to what extent the group finished the task. Students' attention during teacher's introduction, initiatives for participation in science and initiatives for participation in procedure were evaluated on the scale high–intermediate–low. Dynamics of group work and task completion were evaluated on the scale good–intermediate–poor. Dynamics of group work is considered good when students work together, communicate and progress with the task together, and task completion is considered good when the task is completed in the lesson. Dynamics of group work is considered poor when students don't work and progress together. Thus, the observation follows the process from students' attention and participation during the lesson introduction, through their initiatives for science and procedure and the dynamics of the group work and finally evaluates the task outcomes.

Student interviews followed the observed lesson. The interviews were semi-structured and focussed on students' experiences and motivation in relation to the partnership with scientists as well as to the lesson they just had. Content analysis of the interviews revealed eight categories for student experiences of the partnership, of which most were tightly linked to science. The categories were do something hands-on, do something inquiry-based, do things scientists do, get continuity by following and seeing results of a longer project, do something different, feelings of competence in science, be selected for something special and to participate in competition. The process and results are described in detail in Hellgren (2016). In this chapter the reported interview result for each student consists of i) whether it was positive, neutral or negative, ii) an example quote and iii) which category/categories the answer was categorised in. This provides an overview of experiences from the lesson for the 12 students included in the study.

Merging Results Obtained with Different Methods

Data for each student was aligned in a two-step procedure. In the first step observation data were entered into a table presenting a timeline with students' attention during teachers' introduction, students' initiatives for participation in science, students' initiatives for participation in procedure, dynamics of group work and task completion for each student during the observed lesson (see Table 1). In this table we can follow how each student acted in the various parts of the lesson and see the outcomes.

In the second step, the observation data were reduced to actions in terms of initiatives (towards science and procedure) and outcomes (of group work and lesson content). When actions were reduced, two "approach" or one "intermediate" and one "approach" were marked as +; two "avoid" marked as –; and all the other combinations were marked as 0. When outcomes were reduced, two "good" were

marked as +; two "bad/poor" or one "bad/poor" and one "intermediate" were marked as –; and two "intermediate" were marked as 0. The combination of one 0 and one positive or negative outcome was drawn to the endpoints instead of the middle to highlight differences. This reduction of data was done to make it possible to merge observation data with data from the other sources. In Table 2, students' contextual motivation (intrinsic and extrinsic motivation from questionnaire results), actions and outcomes (observation results) and evaluations (interview results) are aligned.

Results

The results are presented and discussed in three parts. The first two parts relate to the testing of the proposed model and present the results regarding situational motivation in action and the results regarding situational motivation in action in relation to contextual motivation and post-action evaluations. The third part evaluates and discusses the proposed theoretical model. It is important to remember in the discussion of the results and the proposed theoretical model that the primary purpose of this chapter and the study is to test the proposed model. The dataset on which the results are based is small with the aim to give an idea of what kind of knowledge can be obtained by using the proposed model of motivation, a model that sees motivation dynamic and multi-levelled.

Dynamics of Students' Situational Motivation in Action

Analysis of the dynamics of students' situational motivation as a process in action revealed students who engaged and succeeded in all steps of the lesson, students who overcame obstacles and students who worked hard without reaching the goals (see Table 1). Regarding the overall quality of work, most students worked well in their groups throughout the lesson, took initiatives towards science and/or procedure and completed the task. However, the analysis suggests that the students in the first two classrooms (students with names beginning with D or E) were better able to overcome challenges and complete the task despite few initiatives, than students in the third classroom (with names beginning with F).

Table 1 Dynamics of students' situational motivation during the lesson in the three classrooms, evaluated on 3-point scales

Name	Attention during introduction	Initiatives to science	Initiatives to procedure	Dynamics of group work	Outcome of task
Dean	High	Avoid	Avoid	Intermediate	Intermediate
Desire	High	Avoid	Approach	Good	Good
Dave	High	Approach	Approach	Intermediate	Intermediate
Dora	High	Approach	Approach	Good	Good
Esteban	High	Approach	Approach	Good	Good
Emma	High	Approach	Approach	Good	Good
Eric	High	Approach	Approach	Good	Good
Edwin	High	Intermediate	Intermediate	Bad	Intermediate
Felix	High	Approach	Avoid	Intermediate	Poor
Frida	High	Approach	Approach	Good	Good
Freya	High	Approach	Intermediate	Bad	Poor
Frank	High	Intermediate	Intermediate	Bad	Poor

Combining Results of Contextual and Situational Motivation

Bringing together results from students' contextual motivation and situational motivation, pre-action, action and post-action show a variety of different patterns. First, looking at the students who did well in all phases of classroom work (Dora, Dave, Emma, Eric, Esteban and Frida), we see that they represent different groups: students with high and low motivation, students from different classrooms and students with good and bad experiences from the novel science task (see Table 2). Second, looking at the students who overcame difficulties during the lesson (Dean and Desire), Dean had high intrinsic contextual motivation for science, and Desire had low intrinsic contextual motivation. Yet, both were positive about the lesson when evaluating it. Finally, students whose outcomes did not align with their classroom effort (Edwin, Freya, Felix and Frank) also represented different patterns of intrinsic and extrinsic contextual motivation, and they all had positive experiences.

Table 2 Examples of how students with different initial motivations for science experience and work with the science task

Student	Motivation (IM/EM)	Experience (overall outcome + example quote)	Action (I/O)
Emma	+/−	Positive: inquiry Work freely and talk to friends	+/+
Eric	+/−	Positive: hands-on, understand science Whatever I do is fun; to work and use my skills	+/+
Frida	+/−	Positive: inquiry You can discuss with the person you work with, talk things through and check and see what you find	+/+
Dora	−/−	Positive: no reasons I like science; it is fun when we do things like this	+/+
Esteban	−/−	Negative: no reasons I never liked science; it is difficult; I have problems understanding	+/+
Dave	−/+	Positive: hands-on We could check out all the small fungi in the microscope	+/0
Freya	+/−	Positive: inquiry, continuity To see what happened to the soil samples; everything looked kind of different; one got curious what it was	+/−
Desire	−/−	Positive: hands-on, variation [It was] different to what we usually do in science class; we don't usually stand and dig on bacteria; we don't usually look at bacteria; it is fun with something new	0/+
Edwin	−/+	Positive: understand science One gets to learn new things	0/−
Felix	−/−	–	0/−
Frank	+/+	Positive: continuity, something special Check what we had collected; when you were filming	0/−
Dean	+/−	Positive: hands-on, inquiry, continuity To do this, check the samples; see what different shapes they could have	−/0

D, E and F names belong in different classrooms

Turning to considering these results in relation to the proposed model of motivation, I consider a few of the students. Some students perform as expected. Emma, Eric and Frida all have high intrinsic and low extrinsic contextual motivation for science that should give them good opportunities to succeed. In the classrooms, all three take initiatives towards both science and procedure, and they have good outcomes for the task. Their experiences are positive, Emma and Frida refer the positive aspects of the inquiry-based way of working and Eric thinks whatever he does in science is fun. One explanation according to the model is that these students, all with high intrinsic motivation, form clear goals and intentions for the lesson and initiate action during their teachers' introductions. Affected by opportunities to feel competence, autonomy and relatedness during the lesson, they stay active and take initiatives to engage in the scientific procedure as well as in the science content. Finally, they evaluate their experiences positively and in relation to science.

Other students had outcomes in relation to their intrinsic and extrinsic contextual motivation for science that were not totally expected, for example, Esteban, who has both low intrinsic and extrinsic contextual motivation for science. In the classroom he takes initiatives towards both science and procedure, and he has good outcomes of the task. However, in the evaluation he expresses a negative experience of the lesson and refers this to a stable contextual motivation for science, that is, his general dislike of science. Another student with an unexpected outcome is Desire, who also has low intrinsic and low extrinsic contextual motivation for science. She avoids the science initiatives during the task, but in other aspects shows high motivation in the action stage. Afterwards, she gives a positive evaluation of the lesson referring to its difference to their usual science lessons. Finally, Edwin has low intrinsic and high extrinsic contextual motivation for science. He takes intermediate initiatives towards both science and the scientific procedure, but the group work is not functioning well, which results in deficient outcomes. These three students show dynamic motivation patterns throughout the lesson, and these can be, at least to some degree, explained by what happens in the classroom in interaction with teacher, task and/or peers.

In sum, no patterns between students' contextual motivation and their actions or experiences were found. Students with high and low intrinsic motivation for science were equally likely to engage in and enjoy their participation in the project.

Evaluating the Model

The purpose of this study was to evaluate the theoretical model as a tool to study motivation and learn more about how motivation can be dynamic and relevant in the science classroom. The theoretical framework combining SDT (Deci and Ryan 1985) and HMIEM (Vallerand 2000) with the process model for motivation (Dörnyei 2000) enabled us to look at both students' contextual motivation for science and students' situational motivation in terms of actions in the classroom and evaluation of classroom activities. Since the framework acknowledges motivation as dynamic and focusses on the actions, it was possible to shed light on the parts of the motivation process during the novel science task. Further, the experimental design that included teachers who provided the same task in different classrooms and students with different levels of intrinsic and extrinsic contextual motivation enabled us to gain insights in how students act in the classroom situations when performing the task.

In the first step observation data were presented according to the progress of the lesson. Here, each student's dynamics of activity and engagement could be followed. Among the 12 students, there were those who engaged and succeeded in all steps of the lesson as well as those who overcame obstacles, and those who worked hard without reaching the goals. Thus, different patterns of dynamics during the lesson could be detected. In the second step the observation data were aligned with contextual motivation (questionnaire results) and evaluation (interview results). The 12 students showed different patterns of action, outcomes and evaluations in relation

to their contextual motivation that was determined in the study design. Thus, patterns of situational and contextual motivation could be detected.

However, this is a preliminary and limited study, and it is important to further extend the knowledge regarding motivation in the science classroom and how it can be studied. To do this, I suggest two possible ways forwards based on the results presented in the current chapter. The first would be a careful study of how contextual motivation may be important for students' classroom actions. Such study should involve a larger number of students, and it would be useful to learn about the role of prior experiences in relation to situational motivation. The second would be more detailed observation studies to support a more critical understanding of what happens in the dynamics of motivation in the classroom. This study could reveal details about factors influencing students' motivation, progress, possibilities to overcome obstacles and success with tasks and ultimately how this leads to positive learning experiences and meaningful learning in the science classroom.

Conclusions and Implications

From the study presented in this chapter, we can conclude that the proposed model for studying motivation in the science classroom has the potential to contribute to the theoretical view of motivation as not only being global or contextual but also being situational as a dynamic process bound in a particular complex science context. We can also conclude that the preliminary results from using the model show that science students with various profiles of intrinsic/extrinsic contextual motivation for science did well in the Medicine Hunt. No clear pattern linked to contextual motivation could be detected. Instead, students with both high and low intrinsic and/or extrinsic motivation for science appeared to engage and thrive in the Medicine Hunt. It is, therefore, possible and advisable to design authentic science activities that can be part of the curriculum and reach a broad group of students.

To see motivation as a dynamic and multi-faceted concept supported new ways of combining results from motivation studies in the science classroom. First, the model supported combination of results from using different methods and contributes to motivation research by being a tool to align motivation as measured with questionnaires with motivation as seen through students' actions in the classroom and evaluations in their own words. Second, the model gave indications of ways to move forwards to further explore motivation as a dynamic concept in the science classroom. Thus, the model using theoretical and methodological triangulation to study motivation, as presented in this chapter, has potential to support development of the view of motivation as a process in the science classroom.

Other researchers (e.g. Nolen et al. 2015; Potvin and Hasni 2014; Turner 2001; Turner and Nolen 2015) have recently addressed that more research on motivation from a situational perspective is needed. This study adds to that argument since results from the test of the model indicate that classroom factors are important for students' motivation in the classroom and that motivation can be dynamic throughout

the lesson. The current study did not take a situative perspective but rather explored how questionnaires can be complemented with interviews and observations in a mixed-methods design. This approach to motivation contributes to highlighting the complexity of motivation as a process in the classroom.

From the study presented in this chapter, we can also draw some preliminary conclusions about secondary science students' motivation when working with novel science tasks in a partnership with scientists. Even if students are selected so that they have diverse intrinsic and extrinsic contextual motivation for science, the classroom engagement during the task is high, and student's evaluations are almost exclusively positive. Many earlier studies of students working in apprenticeships are of extra-curricular activities in which students are chosen or chose to participate (e.g. Sadler et al. 2010). To such activities, students with high intrinsic motivation and plans for future participation in science are likely to apply. The findings of this study highlight the need of further studies of projects that include students with both high and low intrinsic and extrinsic motivation for science.

Based on the results showing that student's progress in the different classrooms differ, we can draw attention to implementation as a key step when introducing novel science tasks to students in a school setting. It appears both possible and advisable to design novel science activities that can be part of the curriculum and reach a broad group of students, but how the tasks are implemented can have an impact on student's motivation in action. The evaluation of the proposed model of motivation suggests that working with this model would allow us access the multi-elements of motivation in complex science classroom contexts and better interpret students and provide better support and encouragement to pursue science-based careers.

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Students' Awareness of Working Life Skills in the UK, Finland and Germany

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Introduction

There is a substantial concern in many countries around the world about a deficiency of professionals working in science (Bøe et al. 2011, OECD 2016a). This educational problem has received recognition for decades, and industry continues to report a skills gap (European Commission 2010; Mendick et al. 2017). However, the problem remains. Archer et al. (2014) identified a lack of knowledge about science occupations and negative attitudes behind secondary school students' lack of interest in science-related careers. Moreover, in the same study, they found that images and perceptions of scientists influence students' aspirations in science. In addition, STEM career awareness is essential for engagement, self-efficacy and relevance development (Dorsen et al. 2006). Cohen and Patterson (2012) introduced four cognitive-behavioural factors in career development: relevance, engagement, students' career awareness and self-efficacy. The latter two affects students' science-related career choices (Cleaves 2005) and therefore are particularly relevant for this paper examining students' awareness of science-related careers and particularly knowledge about working life skills and how these are connected with the previous variables.

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Career Awareness

Secondary school students have limited knowledge and understanding of the required competences in STEM careers (Archer et al. 2014; Cleaves 2005). The limited knowledge is often based on stereotyped perceptions and defective information. These stereotypes might result from low visibility of science-related careers in everyday life (Schütte & Köller 2015). In fact, these stereotyped perceptions of science professionals are found in earlier studies including young children's narratives (Tucker-Raymond et al. 2007); children's constructions of science (Archer et al. 2010); pictures in books (Rawson and McCool 2014); and students' perceptions of working life skills needed in science-related careers (Salonen et al. 2017). These perceptions usually describe science and science-related careers as boring, masculine, filled with laboratory work, intellectually demanding and requiring lots of sector-specific knowledge. In addition, students have a strong perception that science-related careers are not that creative and social (Masnick et al. 2010). An exception is Andersen et al. (2014) study that found Danish students with high interest in science having informed and realistic image of scientists and that stereotyped perceptions were primarily positive.

During early adolescence, students generally develop vocational identities from detached stereotyped images of work to a more realistic image of themselves at work (Porfeli and Lee 2012). However, it seems that conceptions of science-related careers are stable through some of the years of adolescence (Masnick et al. 2010) and lower secondary school science may lead students perceiving that science is not for them. Without correcting these images and increasing awareness of diverse science-related careers early enough, young students might not want to pursue science studies and careers in the future (Archer et al. 2010). Therefore, students need accurate information about STEM careers, and this information needs to be part of science (Holmegaard et al. 2014).

Science education, particularly in lower secondary school, needs to narrow this gap between students' self-image and the stereotypical beliefs in order to promote STEM studies. For example, science education should help students imagine themselves as agents of scientific activity, including considering what counts as science in and out of school (Bang and Medin 2010). Participating in various in- and out-of-school activities fosters students' knowledge of professions and gives students possibilities to know and practice their strengths and abilities related with the professions (King and Glackin 2010; Wang 2013). Such activities should include moderately acquired knowledge, linking the career, working life skills and the society together with students' interests and combining the outside of school activities with the inquiries (Salonen et al. 2018). In addition, students should be encouraged to interpret their own experiences, which might be sometimes more important than the actual experiences (Webb-Williams 2017). These positive school science experiences together with career exploration can raise students' career awareness and sense of self-efficacy.

Working Life Skills and Self-Efficacy

Knowledge about working life skills needed in careers are an essential part of career awareness. Some of these working life skills, sometimes referred as the twenty-first century skills, could be specific to science-related careers, but most of them are generic and transferable between careers. A wide range of studies on twenty-first century skills all include many of the same skills but categorise them differently (Binkley et al. 2012; P21 2015; Pellegrino and Hilton 2012). When reviewing different twenty-first century frameworks, Binkley et al. (2012) compiled ten skill categories: creativity and innovation; critical thinking, problem-solving and decision-making; learning to learn, metacognition; communication; collaboration (teamwork); information literacy; ICT literacy; citizenship, local and global; life and career; and personal and social responsibility. They grouped these skill categories into four categories: *Ways of thinking*, *Ways of working*, *Tools for working* and *Living in the world*. Their framework of twenty-first century skills includes knowledge, skills and attitudes/values/ethics. Knowledge includes all the specific knowledge or understanding of the skills. Skills are the abilities and processes that develop in students and are a focus for learning. Attitudes, values and ethics describe behaviour and aptitudes in relation to the skills. These twenty-first century skills are important in STEM careers, and students need to develop their sense of self-efficacy in mastering these skills required in STEM careers (Cohen and Patterson 2012).

Bandura (1977) defined self-efficacy as a belief of ability to succeed in specific situations or tasks. In his theory, he named four sources of individual's self-efficacy beliefs: performance accomplishments, vicarious experiences, verbal persuasion and physiological states. All of these sources may be promoted in science education. However, performance accomplishments, also known as mastery experiences, are naturally a common part of the learning experiences. According to Bandura, students' may augment sense of self-efficacy during science lessons when successfully performing tasks utilising certain skills. Science education typically involves whole class or group activities, in which students can strengthen their self-efficacy beliefs through vicarious experiences, based on a self-appraisal of their own abilities having observed successful performance by their peers using skills whilst performing varying tasks (Bandura 1977). Bandura states that verbal persuasion from authorities such as teachers, role models, other adults or peers can encourage individual's performance. Although physiological feedback, for example, stress or relief, may not directly influence on self-efficacy development, self-efficacy beliefs may be augmented if students feel calm and at ease performing skills and tasks (Bandura 1977).

Self-efficacy is a key variable in Bandura's (1986) social cognitive theory (SCT), which highlights how learning occurs through behavioural, personal and environmental factors. Lent et al. (1994) extended the SCT with cognitive person variables such as self-efficacy expectations, outcome expectations and personal goals acting together with a person's environment and, ultimately, impacting on individual's interest and career development. This social cognitive career theory (SCCT) posits

that personal accomplishments in required skills for a profession extend the feeling of self-efficacy to perform in such tasks (Lent and Brown 2006). Furthermore, self-efficacy beliefs have an effect on career choice and aspirations. These beliefs can be a predictor of career interest (Lent et al. 2010). Students are more likely to pursue a career they perceive themselves to be competent in. Indeed, previous research has revealed that self-efficacy is a significant predictor of students' science performance (Lavonen and Laaksonen 2009) and science career aspirations (Kang and Keinonen 2017).

SCCT suggests that environmental and social supports and barriers affect students' career choice interest indirectly through self-efficacy (Lent et al. 2010). For example, students might be less likely to aspire to science-related careers because of the low visibility of such careers in society or their negative stereotypical perceptions of those careers. Adolescents also lack vivid, clear understanding how these careers can be both socially and personally meaningful, and perhaps most importantly, it is unclear to them how their talents and interests can be useful and valuable towards long-term goals (Jahn and Myers 2015). Improving students' self-efficacy and skills may need restructuring their cognitive processes relating their own abilities with task performance (Lent et al. 1999). Attempts to foster students' self-efficacy in academic and career-related activities with subject-specific efficacy beliefs should also include a focus on the nurturing and development of self-efficacy in more generic skills such as collaboration and communication skills (Lent et al. 1999). Without promoting students' self-efficacy in a variety of working life skills, students might not see their own abilities important and useful in science, and this might have an effect on their future career choices (Cleaves 2005).

Country Comparison in PISA Context

PISA 2015 results show that students in Finland are among the top performers in science and that students in Germany and the United Kingdom (UK) are well above OECD average (OECD 2016a). However, science enjoyment, science self-efficacy and science-related career expectations are much higher among students in the UK than in Finland and Germany. In addition, within the last two factors, the change from 2006 to 2015 is positive and over the OECD average only in the UK. Among these three countries, science enjoyment and self-efficacy have dropped the most in Finland. Moreover, PISA results seem to suggest that students in Finland and Germany rarely enjoy acquiring new knowledge and working on science topics. Even though science-related career expectation has risen in all three countries, career aspiration, particularly in science-related careers in the UK, is substantially higher than in Finland and Germany. In OECD countries, on average, 24.5% of students expect to work in science-related careers, whereas this is the case for 29.1% in the UK, 17.0% in Finland and 15.3% in Germany. Science education has to provide students with learning experiences to acquire knowledge about science-related careers and working life skills. According to SCCT, these learning experiences can

develop students' self-efficacy expectations on such skills and later promote students interest towards science studies and science-related careers. PISA 2015 results (OECD 2016a) also reveal some variation in science teaching between these three countries. In the UK and Germany, science-related extracurricular activities and enquiry-based teaching are more common than in Finland. These kinds of activities may have positive impact on students' science career choices. Teacher-directed science teaching, more common in Finland, has the same positive effect in the UK and Germany, but not in Finland.

Aim of the Study and Research Questions

Students' career awareness and self-efficacy beliefs are key variables in their future career choices. This study focuses on lower secondary school students' awareness of science-related careers, particularly on the knowledge about working life skills, moreover how to relate this awareness with students' self-efficacy in science. Therefore, this study aims to ascertain what kind of skills the students of three different countries link to science-related careers, giving educators a better understanding how to promote science studies and careers more efficiently in science education. This study answers the following two research questions:

- What are students' perceptions of working life skills in science-related careers?
- How these perceptions differ between British, Finnish and German students?

Methodology

The context of this study is the EU project 'Promoting Youth Scientific Career Awareness and its Attractiveness through Multi-stakeholder Co-operation' (MultiCO). MultiCO project's aims are to promote the students' interest in science and their awareness of science career paths and working life skills. The 513 participants in this study were 215 British, 144 Finnish and 154 German students, aged 12–14 years from three different schools participating in the project in each country. During this age in lower secondary school, the students acquire essential information for their later choice of future studies and careers. The students participated in a workshop in which we asked the students in groups of two to three persons to write down all the skills needed in a career and to choose the three most important skills from the skills they listed for each science-related career presented in Table 1. *Careers in science* (CIS) are the ones involved working in scientific field, working exclusively with science topics. *Careers with science* (CWS) are the ones that use scientific knowledge or skills as a tool or source for knowledge and skills. For this study, we chose the CIS and CWS from lists of science-related careers so the career pairs are as high in contrast. This encourages students to discuss about the range of

Table 1 Career pairs used in the data collection

	Careers in science (CIS)	*Careers with science* (CWS)
Group 1	Chemist	Air traffic controller
Group 2	Pharmacist	Software designer
Group 3	Pathologist	Production planner (food industry)
Group 4	Meteorologist	Nurse
Group 5	Geneticist	Horticulturalist
Group 6	Zoologist	Mechatronics mechanic

different careers. The careers also cover most of the science-related career groups listed in PISA 2015 (OECD 2016b) using International Standard Classification of Occupations (ISCO-08).

Workshop data was analysed using content analysis, first with the Finnish data (Salonen et al. 2017), and then expanding it with the UK and German data. The analysis included three main phases: the preparation phase, the organizing phase and the combining phase (cf. Elo and Kyngäs 2008). In the preparation phase, all the Finnish students' answer lists were marked with codes and transcribed. Two authors read the transcriptions and made a decision on analysis based on the data itself. Since the data were mainly a list of skills, there was no need for open coding, and it was possible to use the skills as units of analysis. In the organizing phase, the skills were freely categorized and grouped. After using this inductive approach of the content analysis process, a deductive approach with an unconstrained analysis matrix based on Binkley et al. (2012) helped to conceptualize new categories, and some categories remained as they were in the analysis matrix. This allowed choosing those aspects that fit into the categorization and use those that did not fit to create one's own categories, based on the principles of inductive content analysis (cf. Elo and Kyngäs 2008). The combining phase included sending the analysis instructions based on the Finnish data to the researchers in each country to analyse their data. Then, the first author gathered and combined the data from all the countries and checked that each skill systematically matched with the categories.

Validity, Reliability and Ethical Considerations

The teachers were instructed to introduce the careers, describing those that were strange and unfamiliar to the students, but not mentioning the skills or abilities necessary to the careers in question. Nevertheless, the teacher's descriptions and help with unfamiliar and difficult careers might have had a minor influence on the students' answers. The workshop with teacher's introduction and the students' group work took approximately 45 min in total. We enhanced reliability with analysis triangulation (Patton 1999); in the first phase, two researchers analysed the data separately, ending up with a similar categorization and analysis of the data that ensured the reliability of further analysis. The autonomy of the participant was respected;

students' consent was asked, and participation was voluntary, giving the students also an opportunity to withdraw from the experiment at any time. Consent was also asked from the parents or their guardians, teachers, schools and/or school administrators. Anonymity of the participants was secured by collecting data anonymously.

Results

The results include 2487 mentions of the working life skills distributed in 12 skill categories and 4 main categories. We present the students' perceptions of working life skills. First, comparing these perceptions between the countries and finally between careers in science and with science.

Working Life Skills in the UK, Finland and Germany

The working life skills mentioned by the students were categorized into 12 skill categories and then into 4 main categories: *Tools for working*, *Ways of working*, *Ways of thinking* and *Living in the world* (cf. Binkley et al. 2012) introduced in Fig. 1. The students in all three countries, particularly in Finland, pointed out that a great deal of *Tools for working* skills are necessary in science-related careers.
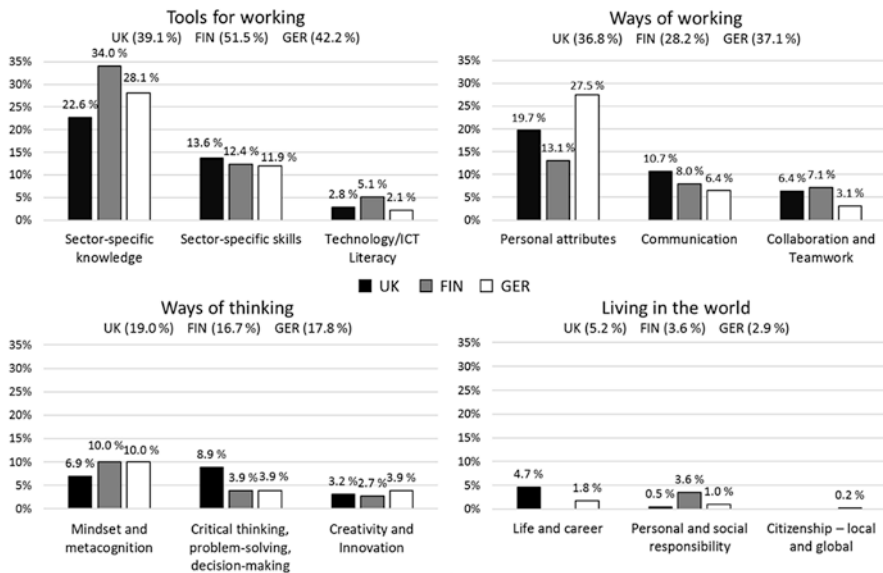

Fig. 1 Distribution of the main categories and skill categories in the dataset

Overall, the students pointed out that a large part of the sector-specific knowledge is needed in all of the careers, with UK and Finnish students mentioning that the sector-specific knowledge was the most needed category in science-related careers. Moreover, Finnish students perceived sector-specific knowledge more necessary their counterparts. In all three countries, the students' perceptions of sector-specific knowledge were focused on school subjects, science and general knowledge. They also perceived sector-specific skills such as scientific, research, manual and technical skills equally important in science-related careers. However, in the UK, the gap between sector-specific knowledge and skills was narrower.

In the UK and Germany, students perceived *Tools for working* and *Ways of working* almost equally important in science-related careers. These students highlighted the *Ways of working* skills, especially personal attributes, more than Finnish students. In this category, the students described attributes or qualities the person working in a particular career needs such as self-confidence, patience, good senses and physical condition. According to them, communication skills are more necessary in science-related careers than collaboration and teamwork skills. The students in the UK perceived communication skills more important than in other countries. Conversely, the German students perceived the collaboration and teamwork skills less important. The Finnish students mentioned skills for both categories almost equally. However, some of the communication skills such as getting along with people, and some of the social skills mentioned, were related with co-operative skills and working together with people.

The students listed substantially less *Ways of thinking* skills than *Tools for working* and *Ways of working* although almost equally importantly in all of the three countries. However, some variation in the skill categories existed. For example, Finnish and German students perceived certain mindset and metacognition skills, such as interest on specific scientific field or career, intelligence, focus and good memory, more necessary than the UK students did. Conversely, students in the UK considered critical thinking, problem-solving and decision-making considerably more necessary in science-related careers than their counterparts. According to all students, creativity and innovation skills are not that important in science-related careers. However, some mindset and metacognition skills were marginally related with creativity and innovation skills.

The *Living in the world skills* with life and career, personal and social responsibility and citizenship skill categories were least mentioned, and some of the categories were not mentioned at all across the three countries. Life and career skills, such as organizational skills and adaptation to working environment, were highlighted by the UK and German students but not by the Finnish students. Even though all students perceived personal and social responsibility somehow necessary, Finnish students mentioned these skills more frequently. Only one skill was mentioned in the category of citizenship - local and global. This skill, ethical consciousness, was mentioned by german students.

Working Life Skills in Careers in Science and Careers with Science

Some variation becomes obvious when comparing the skills mentioned between the *careers in science* (CIS) and *careers with science* (CWS) in total and between the countries (Table 2). In total, students linked CIS more with sector-specific knowledge; personal attributes; communication; collaboration and teamwork; critical thinking, problem-solving and decision-making; and personal and social responsibilities. On the other hand, they perceived CWS to be more closely related with sector-specific skills, technology and ICT literacy and creativity and innovation.

Students in Finland and Germany perceived *Tools for working* more important in CIS than CWS, whereas students in the UK perceived the opposite. Students, particularly in Finland and Germany, highlighted the importance of sector-specific knowledge in CIS. Conversely, sector-specific skills and technology and ICT literacy were more important in CWS.

The personal attributes in the category *Ways of working* were equally associated with both CIS and CWS by the overall sample of students. According to UK students, communication, collaboration and teamwork are needed in CIS more than CWS. Conversely, the German students considered these skills as being needed more in CWS. The Finnish students perceived *Ways of working* equally important to both career groups. However, they linked communication skills more with CIS and collaboration and teamwork more with CWS.

In total, students linked *Ways of thinking* skills equally between the careers. Finnish and German students linked specific mindset and metacognition similarly, whereas UK students were more likely to link those skills with CIS. This difference between countries was also found for higher-order thinking skills such as critical thinking, problem-solving skills and decision-making which are, according to students, more necessary in CIS. Conversely, for all students, CWS are more linked with creativity and innovation skills.

Living in the world skills were linked only with a few careers. However, there is variation between the career groups and countries. Life and career skills were mentioned by UK and German students only, spreading equally between CIS and CWS. Personal and social responsibilities were mostly linked with CIS by Finnish students, who usually referred to job safety, responsibilities and confidence in other people.

Discussion

We have identified and categorized the students' perceptions of the working life skills in science-related careers. Our results build up students' point of view on the earlier studies on skills teaching and assessment (Binkley et al. 2012).

Table 2 Distribution of the categories between *careers in science* (CIS) and *careers with science* (CWS)

	UK		FIN		GER		Total	
	CIS	CWS	CIS	CWS	CIS	CWS	CIS	CWS
Tools for working	**19.0%**	**20.0%**	**28.9%**	**22.6%**	**23.4%**	**18.8%**	**22.3%**	**20.4%**
Sector-specific knowledge	12.4%	10.2%	22.1%	11.9%	18.6%	9.6%	16.0%	10.5%
Sector-specific skills	5.8%	7.9%	5.3%	7.1%	4.5%	7.4%	5.4%	7.6%
Technology/ICT literacy	0.9%	1.9%	1.5%	3.6%	0.4%	1.8%	0.9%	2.3%
Ways of working	**19.7%**	**17.1%**	**14.1%**	**14.1%**	**19.1%**	**18.0%**	**18.3%**	**16.6%**
Personal attributes	10.5%	9.2%	7.0%	6.1%	14.8%	12.7%	10.5%	9.2%
Communication	5.6%	5.1%	4.3%	3.7%	2.9%	3.5%	4.7%	4.5%
Collaboration and teamwork	3.7%	2.7%	2.9%	4.3%	1.4%	1.8%	3.0%	2.9%
Ways of thinking	**10.2%**	**8.7%**	**7.7%**	**9.0%**	**7.6%**	**10.2%**	**9.1%**	**9.1%**
Mindset and metacognition	4.0%	3.0%	5.1%	4.9%	4.9%	5.1%	4.4%	3.9%
Critical thinking, problem-solving, decision-making	5.9%	3.0%	2.2%	1.7%	2.0%	2.0%	4.2%	2.5%
Creativity and innovation	0.4%	2.8%	0.3%	2.4%	0.8%	3.1%	0.4%	2.8%
Living in the world	**2.7%**	**2.5%**	**2.7%**	**0.9%**	**1.6%**	**1.4%**	**2.5%**	**1.8%**
Life and career	2.5%	2.2%	0.0%	0.0%	1.0%	0.8%	1.6%	1.4%
Personal and social responsibility	0.2%	0.3%	2.7%	0.9%	0.4%	0.6%	0.8%	0.5%
Citizenship – Local and global	0.0%	0.0%	0.0%	0.0%	0.2%	0.0%	0.0%	0.0%

The results indicate that students in the UK, Finland and Germany associate working life skills in science-related careers with a large part of *Tools for working* and *Ways of working*, particularly sector-specific knowledge and skills and personal attributes. A possible explanation could be that, in general, traditional science education instruction might give too much focus on activities including theoretical and procedural skills and skills related with acquiring this knowledge (Prince and Felder 2013; OECD 2016a). For example, learning inquiry skills with precise instructions or memorizing formulae. These performance experiences may disregard the development of self-efficacy of students in other working life skills that are essential in science-related careers and might give unrealistic ideas of CIS. These ideas might lead the students to link these careers with numerous characterizing personal attributes that have been found to be stereotypical in previous studies (Archer et al. 2010; Tucker-Raymond et al. 2007; Salonen et al. 2017).

Science education includes a fair amount of pair and group work which should promote, particularly communication and collaboration skills. However, the small proportion of mentions on communication and collaboration skills, together with the support of an earlier study by Lent et al. (1999), highlight the necessity to promote these generic skills together with subject-specific skills. In addition, during opportunities for vicarious learning, each pair or group of students should be equally skilful so that these learning experiences can have the most positive influence on students' self-efficacy (cf. Bandura 1977) and further develop their outcome expectations that these skills are worthwhile in science-related careers. This is also suggested by the low number of mentions about technology and ICT literacy. Students usually are proficient in and have a high self-efficacy using technology and ICT. However, these skills and tools need to be self-evident, or science education would fail to show their importance. Hence, science education should focus on applying technology and ICT more creatively rather than, for example, only for reporting the inquiry results.

Students were less aware of *Ways of thinking* skills in science-related careers. Particularly Finnish and German students rarely related higher-order thinking skills such as critical thinking, problem-solving and decision-making with the science-related careers. These skills are not necessary and thus not promoted in the school context activities and assignments, which might be too closed and include problems set in advance. These assignments can also include strict and detailed instructions with methods, tools and equipment given in advance. This might result in students rarely linking creativity and innovation with scientific careers, thus supporting the study by Masnick et al. (2010). Therefore, school science should include more open problems and open-ended inquiries with less instruction and more student interactions with each other, teacher and most importantly with professionals (Salonen et al. 2018; Carlone and Johnson 2007) to raise knowledge and self-efficacy in these skills. Without the possibility to make their own decisions and use creativity in science learning, students do not develop a sense of knowing their own strength and abilities in STEM careers (King and Glackin 2010; Wang 2013).

The low percentage of *Living in the world* skills reveals that students are not yet pondering their future life and careers or responsibilities as active participants in

working life or society. Science education should provide learning experiences including wide-ranging issues concerning local, national and global issues. This society participation together with professionals could lead to better understanding of the necessary careers, working life skills and responsibilities in the society. These socio-scientific learning experiences could also include persuasion from professionals as role models or from teachers to promote students self-efficacy beliefs. These experiences increase students' appreciation of one's own and other's opinions and outcome expectations and develop efficacy beliefs in life, career and citizenship skills (cf. Osborne and Dillon 2008).

Some variation is obvious in students' perceptions of the working life skills between the career types. For example, CIS are more sector-specific knowledge-oriented and CWS skill-oriented. In addition, technology and ICT literacy are more important in CWS than in CIS. This skill orientation could proceed from students having closer relation with CWS and if these careers are more visible in the society (cf. Schütte and Köller 2015). These social supports and barriers affect students' self-efficacy beliefs and subsequently on their perceptions and interests on these careers as proposed in earlier studies (Lent et al. 2010).

Even though students perceived *Ways of working* and *Ways of thinking* skills almost equally important in both CIS and CWS, our results suggest that students link both career types with different types of characteristics including mindsets and personal attributes. These descriptions of the careers align with the earlier studies (Archer et al. 2010; Salonen et al. 2017) finding that students indeed have stereotyped perceptions of scientific careers. In addition, the students linked critical thinking, problem-solving and decision-making more with CIS. Conversely, they linked creativity and innovation skills more with CWS. This supports the earlier study by Masnick et al. (2010) that students do not perceive scientific careers creative.

The students' knowledge of the working life skills varied only a little between the UK, Finland and Germany. This similarity can result from alike school systems and science education in these countries. However, the students in the UK linked higher-order thinking skills with the science-related careers, especially with CIS, considerably more than in Finland and Germany. Reviewing the results in contrast of PISA 2015 results provides interconnections between self-efficacy, career aspirations and enjoyment in science and the students' perceptions of the working life skills. For example, Finnish and German students have lower self-efficacy and career expectations in science than British students (OECD 2016a) and list more sector-specific knowledge and less sector-specific skills, communication skills and critical thinking, problem-solving and decision-making skills. Finnish and German students rarely enjoying science work and acquiring new scientific knowledge (OECD 2016a) together with perceived large number of sector-specific knowledge lead to lack of engagement in scientific activities (cf. Bang and Medin 2010) and further imagining themselves in those occupations.

In sum, science education should include career exploration, open-ended inquiries and interactions between peers and professionals to promote students' career and working life skills awareness, which are essential for self-efficacy and relevance development (Dorsen et al. 2006; Carlone and Johnson 2007). These experiences

could also promote students' understanding of how their current knowledge and skills are worthwhile (Jahn and Myers 2015) and correct misunderstandings related with the science-related careers and the working life skills required in those careers (Archer et al. 2010). Implementing these elements to science education students can have learning experiences with positive effects on their self-efficacy beliefs in working life skills and more probably pursue science studies and careers as students more likely choose a career they perceive being competent in (Lent et al. 2010).

Conclusions

Results reveal that although the students have a great deal of knowledge about working life skills, it is often just stereotypical. They frequently mentioned sector-specific knowledge and skills but omitted skills related to society, organization, time and career. The students perceived CWS more skill-oriented, creative, innovative, and technology and ICT. Conversely, students perceived CIS as more knowledge-oriented, particularly by Finnish and German students and requiring more higher-order thinking skills by students from the UK and Finland. These differences imply that it is easier for students to relate familiar and practical skills with CWS and list sector-specific knowledge they have learned and, usually stereotyped, characterization with CIS.

Science education, at best, can offer the students with learning experiences promoting wide-ranging knowledge of the science-related careers and the needed working life skills. During these experiences, students' self-efficacy with these skills can develop. The expectations in self-efficacy together with social support from parents, teachers and peers can promote interest in future science studies and careers. Science education activities in and out of school are important sources of students' awareness of careers and required working life skills. Therefore, it is important for educators to be aware of the skills students' link with science-related careers. With this information in mind, they can plan lessons to promote reliable and authentic views of the careers and skills. This kind of teaching helps students to see both, their already acquired and yet to be learned skills more valuable and relevant with science-related careers, school science and science in society. These perceptions, together with the support and feedback from teachers and scientific role models, can increase students' self-efficacy on those skills and further enhance interest on science studies and careers. The EU project MultiCO continues to design, research and provide innovative scientific career-related instruction promoting the above.

For further research, longitudinal studies are implemented about the change and progress in students' awareness of careers and working life skills and what are the students' efficacy beliefs on those working life skills. Future research should concentrate on differences between gender's perceptions of working life skills. Students' career choices might also give more information of what can be done to promote science careers more efficiently and to deliver a more accurate picture about students' science identity, self-efficacy perceptions and role of science and scientific careers in their lives.

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Participation and Learner Trajectories in Computing Education

Anne-Kathrin Peters (ID)

Introduction

There is a long history of concern about engagement in STEM and the diversity of people engaging in STEM fields (Lövheim 2014). Shortfalls of computing professionals are announced nearly everyday (Lehman et al. 2016). Women are continuously under-represented in computer science despite decades of research trying to address the problem. In fact, computer science is the only STEM major where the representation of women has even decreased in recent years (Beyer 2014). This is worrying considering the great impact technology has on our lives. Women are not to the same extent included in the digitalisation process of our society as men.

Decades of research aiming to better understand and address problems of engagement, drop out and under-representation conclude that researchers should shift focus from investigating students' lack of interests, skills, and attitudes to a broader perspective on students' interaction with the learning environment as a long-term process (Ulriksen et al. 2010; Tinto 2006). The notion of identity has been described as the "missing link" in investigating learning in relation to the social environment (Sfard and Prusak 2005), and different theories of identity have been applied to understand and develop education in recent years (Jackson and Pozzer 2015).

In computer science education research, an emphasis lies on understanding cognitive processes and programming (Simon 2015; Tenenberg and Knobelsdorf 2014). Low engagement and under-representation are frequently explained with misconceptions and narrow or stereotypical conceptions of computing, e.g. computer science being equated with programming (Rommes et al. 2007; ACM/IEEE 2013; Denning et al. 2017). The findings of the present study show that computing actu-

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ally can be constructed in narrow ways at university and positioned in ways that marginalise or exclude people with broader interests in computing.

A longitudinal study has been conducted with the aim of exploring computing students' changing relationship to their field of study during their university education. Students from two study programmes (CS and IT) were selected to follow through interviews at the end of the first three study years. An early insight that majorly affected the approach to analyse the data was that students' reflections on their interests in computing can change drastically, e.g. from being someone interested in combining art and computing to being interested in back-end problem-solving, solving difficult technical problems developing solutions that are hardly visible, actually hardly noticeable, to other people.

Social identity theories help to reason about changes in student reflections. Being part of the university environment, the students get to be a part of different social contexts, in which what it means to engage in computing is negotiated. Certain ways of doing, thinking, and feeling in relation to computing are more valued or of higher status than others. This affects and constrains an individual's development as a computing person. The approach to understanding learner trajectories into, within, and out of computing has therefore been to study what the longitudinal data reveals about computing as a social construct in different years, as well as how this explains individual trajectories. The research questions were the following:

RQ1: What are different ways in which the students experience participation in their field of study (CS/IT), at different times of their study?
RQ2: How can insights from RQ1 and social identity theory be used to reason about learner trajectories as a social construct?

The following section provides an overview of the social identity theory that the study builds on. After that, the data collection and analysis are explained, and the results are presented and discussed.

Social Identity Theory

Jackson and Pozzer (2015) identify two approaches to studying identity, the nego-tiation approach and the possession approach. In the possession approach, identity is viewed as something that is possessed by an individual; researchers also use the term "core identity", and they talk about a learner's identity. Such a notion of iden-tity is similar to terms such as "personality" or "individual characteristics". The negotiation approach, in contrast, views identity as something that is constructed in social interaction. Researchers use this notion of identity to understand how indi-viduals are shaped and constrained by social interaction. It is commonly applied to understand inclusion, exclusion, or equity issues.

Studying "different forms of participation" is a natural focus within the negotia-tion approach according to Jackson and Pozzer (p. 227), as it contributes to a better understanding of ways of being as it is negotiated in social interaction. Jackson and Pozzer do however not explain what they mean by participation. Lave and Wenger

(Lave and Wenger 1991; Wenger 1999) describe participation in a way that has inspired the analysis of the longitudinal data collected in this study.

Lave and Wenger have conducted ethnographic studies in communities of practices, mostly in workplaces, that resulted in a learning theory referred to as "situated learning theory" or "social theory of learning". Their theory has been widely used to investigate, discuss, and develop school and university education; in fact it is the most commonly used theoretical framework in research on science identities (Shanahan 2009). It has however mostly been applied with the intention to understand learners as agents of their learning and becoming (Shanahan 2009). Agency is an important concept in social identity literature; it is about how much a person consciously chooses or determines who he or she becomes. Theories that question agency argue that people are shaped by discourse and social interaction (Burr 2003). The present work only uses parts of Lave and Wenger's framework; the degree of agency people have is an open question.

Wenger (1999) describes *identity* as a "way of talking about how learning changes who we are and creates personal histories of becoming in the context of our communities" (p. 5). Wenger's definition of communities, or communities of practice, is rather specific. I have found it difficult to apply it in the context of higher education. I chose to explore how histories are shaped in experiences of participation, participation as it is negotiated in social interaction in different more or less well-established or defined social contexts, e.g. interaction among a group of friends, in a family, between classmates and with teachers, or at a workplace. The professional field of computing can be seen as many different communities of practices, as Danielsson argues (2009), that higher education prepares students to navigate (Wenger-Trayner et al. 2014).

Participation is described as one of the two processes in which identity is formed. It is described as a "complex process that combines doing, thinking, feeling, talking, and belonging. It involves people as a whole, their bodies, minds, emotions, and social relations" (Wenger 1999, p. 56–57). The other process that Lave and Wenger view as crucial for identity development is reification. Reification gives form to experiences; it is about the production of objects, e.g. symbols, words, forms, etc., that congeal social experience into a thing that can be referred to and used in participation. Participation and reification are described as dialectically intertwined; however in this work the focus was to understand participation.

Wenger explains that participation shapes histories of becoming because it is a context for mutual recognition. For example, if two students sit together and program, they negotiate how to do and think when programming, as well as what to find interesting, fun, or difficult. The students can acknowledge each other as contributing to the programming activity; they might recognise each other as knowledgeable in programming and by doing so reinforce or shape their histories of becoming.

The present work describes participation as it is experienced by the students and explores how participation shapes and constrains learner trajectories into, within, and out of computing. The identity literature uses the terms power or power relations to describe how social contexts shape and constrain individual development. Power relations should not only be understood as constraining individuals, but as the

condition of a subject's existence (Butler 1997). Participation is viewed as a context in which power relations come to play.

Another relevant notion for this work has been uniformity, to acknowledge that people may act differently in different social contexts. In general, the view of identity as an integral, unified identity has been criticised in a variety of disciplinary areas (Hall 1996). This work acknowledges that a learner may talk about his- or herself as a computing person and experiences with computing differently in different social contexts, e.g. when talking to me, peer students, teachers, or family and friends outside university.

Data Collection

The research was conducted at a Swedish university. All students that commenced the two study programmes computer science (CS) and Computer and Information Engineering (IT) in 2012 got a mandatory assignment to reflect on their choice of study, their career aspirations, and their expectations for their studies in a written essay. From these essays, I selected 25 students with different backgrounds to follow through interviews at the end of each of the first 3 study years, of which 23 students agreed to participate in this longitudinal study. After the third-year interviews, I invited all participants to discuss the results of this longitudinal study in two groups consisting of three–five CS students and three–four IT students. Figure 1 illustrates the data collection process.
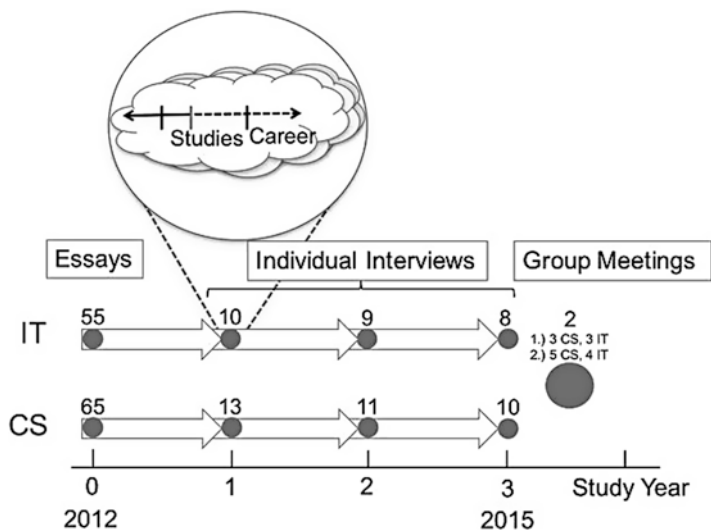

Fig. 1 An illustration of the data collection. The green circles represent an instance of the data collection. The numbers above show the number of participants

The selection of the students is based on 123 essays (of 149 students that were enrolled). Only seven of the essays were written by female students, all were invited, and six female students agreed to participate. Out of the 116 male students, I aimed to select about equally many CS and IT students and about equally many students with and without (a) CS/IT at school, (b) study experiences (CS-related and not), (c) job experiences (CS-related and not), (d) a stated interest in computers, and (e) other interests such as problem-solving, programming, etc. The selection is described in detail in (Peters 2014). Each of the interviews was semi-structured (Kvale 1996) and about 1-hour long. All interviews consisted of four parts: (1) choice of study, (2) ideas for future career, (3) experiences during the last study year, and (4) development during the studies and views of CS/IT.

The group meetings aimed to discuss the results of the longitudinal study with the participants of this study to increase the trustworthiness of the results but also to get additional insights (see Peters 2017 for details). Each group meeting lasted for about 2 hours. A group of CS and a group of IT students were given sticky notes with keywords on aspects of participation in CS/IT, e.g. "coding" and "helping people". The students placed the keywords on a poster with a scale ranging from "came in contact all the time" to "never came in contact with". The two posters of the CS and the IT students were compared and used as a starting point to discuss participation and learner trajectories with the students.

Jackson and Pozzer (2015) argue that interviews are typically used to understand identity as possessed by an individual. However, the focus of the interviews was to understand social interaction and the social contexts that the students were a part of. The goal was to understand students' histories or trajectories as a more or less conscious response to social interaction.

Data Analysis

The interviews were transcribed. All transcripts were read, and excerpts that included doing, thinking, and feeling and social relations were marked. Labels were used to capture the meanings in the excerpts.

Phenomenography (Marton and Booth 1997) guided the analysis of students' experiences of participation in CS/IT. Phenomenography is a research approach useful to investigate different ways in which learners come to experience a phenomenon during education. Marton and Booth define a phenomenon as an entity that transcends the situation. A preliminary analysis of the interviews indicated that participation in CS/IT can be seen as a phenomenon as the students encounter certain ways of doing, thinking, and feeling in certain social contexts in different situations.

The aim in phenomenography is not to describe individuals' conceptions or experiences of a phenomenon but instead ways of experiencing the phenomenon that exist in a cohort of learners. By describing participation as it is described by the learners of this longitudinal study, I describe participation as it is observed by these learners, instead of describing solely my own observations of participation and social interaction. Choosing a cohort of students that together cover a breadth of experiences, the phenomenographic analysis aims to capture the variation in experiences.

In the analysis, the researcher studies and describes the structural and referential aspect of a way of experiencing the phenomenon. The structural aspect is about the parts internal and external to the phenomenon. The referential aspect refers to the meaning that is assigned to a phenomenon. For example, in order to experience a table as a table, we need to discern the legs of the table and the table board, these parts have to be distinguished from their environment, and a meaning has to be assigned, e.g. something to sit at to eat. The structural and referential aspects are "dialectically intertwined".

The result of a phenomenographic analysis is an outcome space with a limited set of categories that each describes a way of experiencing the phenomenon. Phenomenography assumes that the categories of the outcome space relate to one another because each category is a different perspective on the same thing.

The phenomenographic analysis conducted here was iterative. Tentative categories that would describe the different ways of experiencing participation in CS/IT were identified, and their relationships were described. The categories were refined in a process of working with the description of the categories, re-visiting the data, and discussing the results with other researchers in the research group.

Results

The analysis resulted in an outcome space describing seven different ways in which the students experience participation in CS/IT (RQ1). Each way of experiencing participation is characterised by an aim that the participants share and a social context that a certain way of experiencing participation is shared within. The insights into participation are used to discuss learner trajectories, drawing on examples of learners followed in the longitudinal study (RQ 2).

Participation in CS/IT

The analyses of CS and IT students' experiences of participation result in one outcome space. The curriculum of the two study programmes are very similar, and the students take most of the courses together, so they interact with each other and shape each other's experiences of participation. Table 1 is a summary of the outcome

Table 1 Categories describing qualitatively different ways, in which the CS and IT students experience the phenomenon participation in CS/IT in the first, second, and third study year

Participation in CS/IT is experienced as…	Shared aim	Social Contexts
A … using	Draw benefit from an artefact	Various, e.g. family, peers, school and university contexts (particularly shared among students), professional environments
B … learning about technology	Change of self	
C … creating	Create a new CS/IT artefact	
D … (technical) problem-solving	Overcome a barrier (solve a difficult problem)	University contexts, contexts around students that work on projects, professional environments
E … problem-solving for others	Help other people that may not work in the field of CS/IT	HCI contexts, i.e. course of the third study year and later courses, contexts around students that work on projects, professional contexts
F … creating new knowledge	Knowledge that can change how CS/IT people work	University contexts at the end of study year 3 and in subsequent years, professional contexts
G … contributing to societal endeavours	Developing society	Professional contexts

space describing qualitatively different ways of experiencing participation in CS/IT. The categories are inclusive, i.e. experiences described by one category include experiences described by the previous categories. The labels in the column to the left capture the meaning of an experience of participation. The description of the shared aim focuses on describing the new aspect or focus of the shared aim. The social contexts become more and more specific.

Three categories appear to be particularly relevant to understand learning and becoming in computing education, participation as creating (category C), (technical) problem-solving (category D), and problem-solving for others (category E), which is why I focus on describing those experiences of participation in the following. I found few reflections that fell into participation as creating new knowledge (category F), and those were about future engagement. Only one reflection was about participation as contributing to societal endeavours (category G), a reflection in one of the third-year interviews. All categories are described in (Peters 2018), an article that also presents two more outcome spaces providing nuanced insights into participation as problem-solving and problem-solving for others.

Participation as *creating* (category C) is about building new technical or digital artefacts. Being able to create new artefacts is experienced as fun and fascinating. Participation as creating is shared among the students in particular. Several students told me, the interviewer, that the students sit together in between or after classes and brainstorm ideas for different "mini-projects" that they could engage in outside class, for instance, developing an app or a game:

> Jaylin[1] (CS, year 3): [As a student], you discuss […] different mini-projects that you are engaged in. [… For example,] one person was doing some kind of a blinking light-thing for a jacket, so he had a little arduino kit that he programmed. […] Or I have another friend who used an arduino kit to lift and lower the roller blinds. It was controlled by a mobile phone and light.

Participation as *(technical) problem-solving* (category D) is about using methods and ways of thinking to approach difficult (technical) problems. The aim is to create a solution; thus the experience described by this category includes the experience described by category C. The participants do not only create a solution; they also create and design the process to develop the solution. Many students talk about the method "divide and conquer" to approach a problem. It entails identifying and working on subproblems and integrating subsolutions into a complete solution. Participation in problem-solving can be more abstract than participation as creating in the sense that the concrete or overarching application is out of sight. The education is experienced to be about learning to solve different types of (sub-) problems. Several students specify the kind of problems of interest as "back-end" problems. "Back-end" problems are seen as the really difficult problems. Their solutions are hardly visible, actually hardly noticeable to users.

Participation as problem-solving is predominant in the university learning environment. It is experienced as the core of computer science. The following quote clearly demonstrates this. Amari talks about the "bible", a book on data structures and algorithms, which are seen as important tools for problem-solving in CS/IT. This book is recommended to younger students, as "the bible", by older students. It shows the importance of students in passing on what is central and of value to new student generations.

> Amari (CS, year 3): We have this bible, […] a thick book which contains a lot of algorithms […] and data structures. [… It] is very complete, […] it contains only necessary text.
> I: How did you use it?
> Amari: […] The book contains a list of different algorithms that you can go through to see: "*That algorithm is suitable for this problem!*".
> I: How did the book get the name bible?
> Amari: […] Older students have called the book "*the bible*", because for many students, CS is all about algorithms and data structures.

In study year 3, the students get to be a part of participation as problem-solving for others (category E) in the human-computer interaction (HCI) course. The course introduces the students to different methods, ways of thinking, and best practices to improve the users' experience. The human comes into the fore in new ways. The previous category, participation as problem-solving, includes working with other people to be able to solve difficult (technical) problems. In participation as problem-solving for others, the person using and having use of a solution and the application

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[1] The names are not the students' real names. In order to protect anonymity of the very few female students in the study, I am using names that I found to be gender neutral and only male pronouns to preserve the masculine atmosphere in the student cohort. All quotes were translated from Swedish to English in a way that resembles the original as much as possible, which may lead to slightly uncommon English sentences. "I" stands for "interviewer", the author of this report.

context are in the fore. The participants share positive feelings connected to working on something that is beneficial for someone else. The following quote by Finley suggests that this way of participating is specific to the HCI course:

> Finley (CS, year 3): "[The HCI course was about] improving a user's interaction with a program. […]. We got to do a study in which we looked at existing systems. We tried to identify what is good and what could be improved, we tried to do interviews with users […]. That was quite interesting, something that I didn't think about earlier".

Several students rejected the HCI course as very different or out of the scope of their field of study, as, for example, Remy in the following:

> Remy (CS, year 3): [HCI] is so fuzzy! Everything else is like: "It is important that it is scientific!" […] CS is very mathematical, 1+1 = 2. But HCI […] is not mathematical, it is more like: "As those people experience this like that, we know it is good!" You don't prove it with math.

The statements of rejection have in common that they position CS/IT as engaging in technical as opposed to social questions, as being objective and not engaging with subjective user experience, and as theoretical as opposed to dealing with applied and broader societal questions. They can be interpreted as another way of participating in CS/IT, which I call *technical problem-solving*, meaning problem-solving as opposed to problem-solving for others.

Trajectories Into, Within, and Away From Computing

Participation has implications for learner trajectories. Using Wenger's words, participation shapes histories of becoming. Considering identity literature, participation can also constrain individual development.

Participation as creating is a way of engaging in CS/IT that many students experience already prior to studying. The interest in creating technical artefacts is something that many students share; it is something that ties them together. The individual student can be part of the social context of students through expressing an interest in creating and demonstrating his or her competence in creating technical competence. Participation in creating can make students feel that they belong to a group of students, and it can shape students' histories of becoming and being a computing student and future professional.

There are however also students that decide to leave the study programme because they do not share an interest in creating apps and games as the other students do:

> Ellis (IT, left after 1 year): "I am interested in playing games, but it is not like I want to develop games, which was what my friends mainly focused on".
> Jamie (CS, year 1, left after one semester): "The new programme [electronics] is about getting different components to work together, rather than what it is here, to develop an app".

These student accounts show that the predominance of participation as creating can also turn people away from computing. All students that remained in the study

programme either brought with them an interest in problem-solving or stated such an interest in an interview at some point. Several students explained that they have become better at solving difficult problems and that they find it fun. Students develop an interest and competence in problem-solving, but it could also be necessary to develop such interests and competencies related to problem-solving to fit in and be recognised as a computer science student. Becoming a participant in (technical) problem-solving seems to be a common trajectory for computing students in this learning environment.

The learning environment does however not encourage trajectories into being someone that engages with the users, their needs, and experiences, i.e. trajectories into being problem-solvers for others. Those who show enthusiasm for problem-solving for others risk being questioned as computer scientists, as, for example, the teacher of the HCI course:

> Chris (CS, year 3): "The teacher [of the HCI course] was very interested in HCI. […] We thought: 'He is not a real computer scientist!'(laughs). But then it turned out that he actually could program and that he was as good as we are, […] just that he had an interest in that which was a bit fuzzy".

The people who show an interest in the users and social questions are suspected to be incapable of programming by those people who perform as (technical) problem-solvers. They are challenged to prove their programming competencies. This was explicated in one of the group meetings, in which a student said that he considered choosing HCI as a specialisation but changed his mind when other students told him: "Those who choose HCI, they are those who cannot code, those who slide through the first 3 years of their education". This again demonstrates what is important to achieve as a part of studying, becoming someone that is good at solving technical problems by programming or writing code.

Performing as a technical problem-solver is a way to position oneself as a computer scientist through demonstrating an interest in that which is seen as central. This could explain why students perform as a technical problem-solver, rejecting aspects beyond the technical, even though they expressed broader interests in the beginning of their studies. Matthew, for example, entered the study programme when he had almost finished a political science degree programme. In the beginning of his study, Matthew believed that he has used his competences developed in the political science degree programme in computing, arguing:

> Matthew (CS, year 1): "The connection between CS and political science comes naturally".

In the interview at the end of the second study year, Matthew said that he does not think about politics anymore and that he now is interested in back-end programming. In the third study year, Matthew positions himself as a pure computer scientist, not interested in interdisciplinary work:

> Matthew (CS, year 3): I think, one misses a lot when combining politics and CS. […] Political science […] is about discussion […] without getting anywhere. […] The only way to come to a point of right or wrong is to look at reality. [… In CS] it often feels like […] I want to do a better solution […]

> One tries: Can I do this algorithm slightly, slightly faster? As this is a theoretical, a natural science discipline, one can always test the solution […] in a very small, secure environment.

The importance of participation as problem-solving and demonstrating competence as a problem-solver can encourage trajectories into being technical problem-solvers. These arguments fit together with the following explanations of students leaving the study program. The students have an interest in social and societal aspects, helping people, and are choosing different study programmes to pursue these interests:

> Henning (IT, year 2, left after third semester): "I feel that it [the IT study programme] is nothing that interests me. I just want to make a difference for a person".
>
> Ellis (IT, left after 1 year): "[I changed the study programme because] I want to either do something for the environment or work within the field of medicine. […] It should lead to something good, […] a bit of a saving the world feeling".

The predominance of participation as (technical) problem-solving or the inaccessibility of contexts where it is safe to perform as a problem-solver for others can cause people to leave computing.

Discussion

The findings of this study are in-line with Schulte and Knobelsdorf's (2007) results analysing novice computer science students' computer biographies. As in the present report, Schulte and Knobelsdorf present experiences of creating as an entrance point into computing. The present research however suggests that participation as creating technical experiences can also be experienced as too narrow. Students decide to leave the field of computing because they cannot make sense of themselves as someone that engages in creating apps and games.

Longitudinal studies are rare but there is a similar study in which Danish students were followed from high school to university using narrative interviews (Holmegaard et al. 2014, Ulriksen and Holmegaard 2016). The researchers argue that the choice of study should be seen as a process that continues for at least a year after the students commence their studies. The students try to make sense of their study experiences and to construct a narrative about who they are in relation to their field of study that would be accepted by different other people. The present study confirms these results and suggests that students in computing integrate predominant experiences of participation as creating and (technical) problem-solving into their narratives of who they are. Students with an interest in social and societal aspects have difficulties understanding who they are because such interests are not encouraged by the university learning environment. Ulriksen (2009) argues that the curriculum implies a certain type of student, e.g. one that tolerates toolbox courses and narrow constructions of the discipline in the beginning of the study programme. The curriculum of the education programmes studied in the present research implies a student that can perform as a and identify with being a participant in participation as creating and (technical) problem solving.

Investigations of technology and science with gender perspectives illuminate the results presented here. Technology and masculinity are found to be co-produced (Faulkner 2001; Ottemo 2015). Dichotomies are used to establish and position technology and masculinity, e.g. technical vs. social, objectivity vs. subjectivity, and theory vs. application (Harding 1986; Faulkner 2001; Mendick 2005). Positioning computing as dealing with technology, machines, and not social aspects is a way to perform both masculinity and a computing identity. Questioning, degrading, or excluding social aspects reproduces the hegemony of certain ways of doing computing and of masculinity compared to femininity. The focus in participation as creating is to build artefacts, which is also connected to masculinity (Boivie 2010).

The present research identifies a gap between views of computing as essential for society (Lövheim 2014; ACM/IEEE 2013) and constructions of computing in this university environment. Becoming someone that works for other people or society is not encouraged by the learning environment. Women and different experiences and competencies in general are seen as important for the development of technology for all (Beyer 2014; Margolis and Fisher 2002), but this study suggests that broader and different ways of thinking, doing, and feeling actually may not be appreciated. Disciplinary boundaries and the kind of people engaging in the field seem to be reproduced in education.

Conclusion

The present chapter has discussed the relationship between participation and learner trajectories in computing education at university. Participation allows to study engagement and becoming in computing as a holistic process that includes social relations and emotions. Emotions are an important and still under-explored aspect of learning (Zembylas 2016).

Participation as creating and (technical) problem solving appear to be predominant in the learning environment studied here. The students learn to make sense of themselves as someone participating in such ways and direct their learning efforts towards acquiring the necessary competencies. In the third study year, a way of participating in problem solving appears in which broader, social aspects are seen but rejected, i.e. CS/IT is positioned as purely technical. Participating in such a way can be explained as a behaviour to make others believe in one's technical competencies, which seems to be of great importance to gain recognition in this learning environment.

The study shows that it is important to rethink the design of computing education. Introducing broader experiences of computing late appears to be a breeding ground for dualistic and narrow constructions of computing that are associated with masculinity. Striving for diversity, educators need to create learning environments that allow students to experience diverse ways of engaging in computing early on.

That way, our society can gain more people knowledgeable in computing that also bring in other experiences and interests that are valuable to develop the sustainable, digitalised society of our future.

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Addressing Complexity in Science|Environment|Health Pedagogy

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Introduction

The Churchill Effect

Marie-Louise Wirth is a barkeeper in the small village of Isbergues in Northern France, south of Dunkirk. This year she turned 100 years old, and, when asked for her secret to a long life, she said that it was a glass of cherry brandy each day. Furthermore, as she assured, she "swears by everything that you shouldn't do", such

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as eating mayonnaise and gherkins, but never fruit. And, as she added, "she never liked walking, she prefers driving cars".

This remarkable old lady, recently featured in a well-read free Swiss newspaper, is surely the nightmare of every health and environmental educator, just as Winston Churchill was. England's famous prime minister in the Second World War used to reply to the question about the secret of his long life: "Cigars, no sports". This became a catch phrase, for many years, for all sceptics of public health.

How should one respond to all the Wirths and Churchills of this world? We argue that the *Churchill effect* is a typical effect of complexity, that health and the environment are paradigmatically complex, and that a pedagogy seeking to exploit the mutual benefits of these educational areas has to take into account effects of complexity and help students deal with them in an appropriate way.

Don't Predict, Adapt

The interesting point about complexity is that it, in principle, does not allow for prediction. However, in most science-oriented approaches and, thus, also in environmental, health and science education, scientific prediction plays a prominent role and is the epistemological twin of scientific explanation (e.g. Rosenberg 2005). Actually, most health and environmental guidelines are based on scientific knowledge and ask for sound action based on predictions of "good" or "bad" outcomes. Thus, the art of decision-making in complex contexts is to take scientific knowledge into account but to interpret its meaning in terms of concrete complex contexts.

There is no point putting up a warning finger and saying "Be careful, Churchill was just a lucky guy" and predicting "… but statistics say that your chance will be small (if not zero) to be as lucky yourself!" Much better would it be to go into Churchill's biography and find out how smoking affected his life, perhaps in a way that he did not notice himself (and probably did not shorten his life span), or to talk to students about the 100-year-old lady and why driving by car may be suitable in her context, but probably not in their—the students'—own situation.

"Don't predict, adapt!" (or *adaptive staging*, as this strategy is also called) is a famous slogan of complexity talk, launched by the theoretical physicist Per Bak in his influential book *The Science of Self-Organized Criticality* (Bak 1996). What does this mean in the context of environment and health? How do we help students understand and apply scientific knowledge in complex real-life contexts? What is health literacy and environmental literacy from this point of view, and what is it not?

This type of considerations is typical for what we call a new Science|Environment|Health pedagogy (e.g. Zeyer and Kyburz-Graber 2012). For

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decades, a culturally-historically perceived antinomy between the culture of science and the culture of health promotion and environmental education has been construed. Stories like those of Marie-Louise Wirth would then have been analysed mainly from a cultural-historical point of view. Indeed, often, the *Churchill effect* would have been misused for illustrating the priority of psychosocial salutogenetic factors over biomedical pathogenetic factors, a stance, by the way, which Antonovsky, the father of salutogenesis, would have utterly disapproved (Antonovsky 1997) and which frequently results in contesting and even neglecting the role of scientific knowledge in these educational areas (Hafen 2007).

The term Science|Environment|Health (Dillon 2012) stands for a pedagogy that ventures to close this gap and to establish a solid link between environmental, health and science education. The basic conviction of this approach is that the ambivalence between science, environment and health education is ill-informed and that, in reality, there is a still underestimated potential for mutual benefit between these three interdependent educational fields (e.g. Zeyer and Dillon 2014).

We first provide some general remarks about complexity and the theory of complex systems. This will be followed by the presentation of four empirical studies on Science|Environment|Health (S|E|H) issues. The final discussion and conclusion revisits these studies from the perspective of complexity. It draws some preliminary conclusions and suggests further research directions.

Ordered Systems and Complex Systems

Systems Theory

The systems-theoretical distinction between ordered and complex systems goes back to the mathematician John von Neumann (von Neumann and Burks 1966). In principle, ordered systems enable complete forecasting and control. In the paradigmatic case, they can be modelled by linear differential equations (e.g. Kellert 1993). Indeed, all established physical theories, including quantum mechanics and both relativity theories, are based on linear differential equations and, thus, on ordered systems. Complex systems cannot be modelled with linear equations. Often, they are characterised by sensitive dependence of initial states, and, in most cases, they do not allow for *prediction* and *control* but ask for dealing with uncertainty and adaptive strategies.

Nevertheless, as life sciences impressively show, complex systems do not need to be chaotic, i.e. erratic and fully unpredictable. Therefore, complexity theory distinguishes between complex and chaotic systems. Both are essentially non-linear, i.e. their time development can—if at all—be described only by non-linear differential equations. However, the former allow for limited prediction, while the latter are fully unpredictable.

The Cynefin Framework

All in all, complexity theory distinguishes between four types of systems. Ordered (linear) systems are simple or complicated. Complex (non-linear) systems are complex or chaotic. The resulting 2 × 2 matrix has been called the *Cynefin framework* (Table 1), originally developed in economics (Snowden et al. 2012). Complicatedness and complexity are often confused, although, from a systems-theoretical point of view, they belong to two completely different worlds. No matter how intellectually challenging a complicated situation may be, careful analysis can be confident of finding a correct solution that entails a proper response. In contrast, complex contexts (and even more so chaotic contexts) do not allow for conclusive analytic solutions. Here, as the *Cynefin framework* points out, probing is needed, i.e. scientific analysis, as sophisticated as it may be, is not sufficient.

Fensham (2012) introduced the *Cynefin framework* into science education and made clear that non-complex contexts, particularly simple contexts, are still much too dominant in science education. He observed that all the great challenges of this century are highly complex, and he concludes that S|E|H issues in their full-blown complexity should be much more prominently represented in science teaching. Similar arguments of other important science education authors can be found frequently in literature (e.g. Abd-El-Khalick and Zeidler 2015).

Another argument comes from research on motivation to learn science. Complex issues can be an important *science for all* drivers, because they beware science teachers from too much "predict and control" teaching that normally appeals only to a small minority of *potential scientists* (e.g. Zeyer 2017).

In the following section, four symposium contributions are presented. They flesh out the challenges of handling complex issues in science education.

Table 1 The Cynefin framework

Ordered systems	Complex systems
Simple contexts	**Complex contexts**
Static linear systems	Non-linear systems
"Fully" predictable	Not predictable
Example: Plant taxonomy	Example: Cardiovascular system
Complicated contexts	**Chaotic contexts**
Dynamic linear systems	Non-linear or "non" systems
Highly predictable	"Fully" unpredictable
Example: Newton mechanics	Example: Stock markets

Adapted from Snowden et al. (2012) and Fensham (2012)

Symposium Contributions

Handling Complexity in Decision-Making Concerning Preventive Health Actions: Grasping Health Knowledge

J. Arnold

An unhealthy diet (e.g. excessive sugar consumption) is seen as an important risk factor for noncommunicable diseases (NCD), e.g. type 2 diabetes, which are the leading causes of mortality in the world (WHO 2016). Hence, it is essential to teach students how to make healthy decisions, especially regarding nutrition. This study elaborates on how health knowledge can be operationalised in order to research how students handle complexity in terms of decision-making concerning preventive health actions such as reducing sugar consumption.

In science education, socio-scientific issues (SSIs), including health issues, usually include moral or ethical dilemmas, and students should learn to make well-thought-through decisions about "current social issues with moral implications embedded in scientific contexts" (Zeidler et al. 2009 p. 74). Furthermore, SSIs are mostly ill-structured, because students are exposed to "problems that involve a number of discrepant scientific, social or moral viewpoints, many of which may conflict with the student's own closely held beliefs" (ibid.). The multidisciplinary rootedness, uncertain knowledge base and ill-structured nature of SSIs also contribute to their complexity (Fensham 2012). There are several health behaviours that are executed with more or less conscious decision-making or without relevant scientific knowledge, like in nutritional topics. Here, decisions rely on personal rather than ethical values, and the underlying problems are less ill-structured and the knowledge base is mostly certain. But still, healthy decisions are quite complex. Many motivational factors, such as perceived susceptibility and perceived severity of associated diseases like type 2 diabetes, efficacy expectations (e.g. concerning the reduction of sugar) and the personal evaluation of this action as unpleasant, expensive or stressful, can play a role in these decision-making processes (Arnold 2018). Furthermore, the expectation that a certain action leads to the desired outcome (e.g. preventing type 2 diabetes) is not calculated easily and is prone to subjective assessments, as well as the value of this outcome. Not to forget social norms, for example, might lead one to eating sweets to be socially recognised. These factors strongly depend on knowledge. Hence, in order to make informed decisions, e.g. in favour of the preventive behaviour to reduce one's sugar consumption, one has to make the different motives and evaluation processes conscious and include the relevant scientific

knowledge. Here, Kaiser and Fuhrer (2003) use a threefold division of knowledge underlying behaviour, which can be transferred to health behaviour:

1. System health knowledge (SK) is the knowledge about health, the body and its (mal-)functioning. This knowledge might influence the evaluation of susceptibility and severity of coming down with diseases like type 2 diabetes. And on the other hand, this can influence the following knowledge types.
2. Action-related health knowledge (AK) is the knowledge about possible actions to preserve functioning and prevent malfunctioning of body and health.
3. Effectiveness health knowledge (EK) is knowledge about the relative potential of actions to lead to the desired prevention of diseases.

The goal of this study is to test whether these health knowledge types can be displayed empirically in order to measure their respective influence on motivational factors and finally on decision-making.

Method and Results

The knowledge types were operationalised in dichotomous items. The test for measuring SK consisted of 27 items (EAP/PV reliability, 0.71; wMNSQ, 0.86–1.15). The test for measuring AK consisted of 20 items (EAP/PV reliability: 0.75; wMNSQ, 0.91–1.1), and finally the test for measuring AK consisted of 20 items (EAP/PV reliability, 0.63; wMNSQ, 0.9–1.13). The sample consisted of N = 115 people aged between 16 and 62 (mean: 29), and 75% of them were female. Multidimensional Rasch analysis (ACER ConQuest software) was applied to analyse the dimensionality of the test. The model's fitting parameters were compared to corresponding parameters of a one-dimensional model using Akaike's information criterion (AIC; Akaike 1981) and Bayes' information criterion (BIC; Wilson et al. 2008).

Analyses show that the information-based criteria are lower for the three-dimensional model (AIC = 8218.68, BIC = 8435.53) than the one-dimensional model (AIC = 8080.30, BIC = 8310.87). Furthermore, a χ^2-test shows that the three-dimensional model significantly outperforms the one-dimensional model ($\chi^2[14] = 56.56$, $p < 0.001$).

Discussion and Conclusion

Model fit statistics indicate that health knowledge concerning the reduction of sugar consumption in favour of type 2 diabetes prevention can be treated as three-dimensional. Nevertheless, this conclusion is limited due to the small sample and the specific context. Next steps in this project will be to further optimise the test and adapt it for other contexts, as well as to apply it to larger samples. Furthermore, we are developing a questionnaire for the assessment of the motivational factors described above in order to be able to test the respective influence of the three

knowledge types. In the long run, we are seeking to teach students how to handle complexity in decision-making processes concerning preventive health actions by making underlying motives conscious and by teaching the different knowledge types of health knowledge.

The Complexity of the Concept of Environmental Health and Competences Acquired by Spanish Youngsters

N. Álvaro · O. Mayoral · V. Gavidia

The concept of environmental health can be understood through two concepts: health and environment, apparently simple but at the same time complex. Just as an ecosystem is a superior entity to the addition of the biocenosis and biotope, the health and environment alliance results in a higher-order concept: environmental health, which we understand under three principles, namely, health literacy, the global idea of the environment and sustainability.

Health is not just about being well but about personal well-being. It is not even enough to take into account social welfare as indicated by the WHO as being "Physical, mental and social well-being" (1948). Health is a process, not a state, in which an internal and personal balance is sought with the environment in which one lives. Being a process, we understand it as the set of actions that facilitate the development in a physical, social, economic and cultural environment, in which society prospers in solidarity and humanly.

The *environment* is no longer just the medium where a certain population lives and is understood as all that surrounds us, visible or invisible, with the forces and relationships that are established between the components of the environment: cultural, social, physical and economic. It is the city, the neighbourhood, the air we breathe, the water we drink, the work we do not do, unemployment, hunger, war, the supply of food, the exchange of ideas, cultural strength, etc.

In this way, *environmental health* is the "flash" that draws the situation of people who form a society in a specific environment and at a specific time. It includes the elements of the environment that affect the health of people, aspects of human health influenced by the environment and the actions of people who affect the environment, considering that they are also part of the environment. Environmental health is the result and the process that seeks the development and evolution of the environment towards its improvement, complexity and stability.

The aim of this research is to study the extent to which Spanish students develop environmental health competences that allow them to integrate in a society in continuous change while attending compulsory education. These competences are specified in Table 2.

For this purpose, a validated questionnaire including four sections was used: (A) personal data (age, gender and study centre); (B) health concept; (C) identification of environmental health problems; and (D) actions towards five specific environ-

Table 2 Competences in environmental health

Competence	"Know, value and contribute to the creation of a healthy environment"
Knowledge	Know the characteristics of a healthy environment and the signs of its deterioration. Effects of the environment on human health
Skill: Know what to do	Caring for the environment, contributing to its improvement and avoiding unhealthy environments
Attitude: Know how to be	Commit to the creation of a healthy environment. Solidarity with those who share the earth and with those who will inherit it

mental health problems such as hunger, consumerism, climate change, pollution of cities and allergies. Each problem was addressed by three questions with an open response focused on the three dimensions: knowledge, skills (know what to do) and attitudes (know how to be).

The sample consisted of 878 students, 438 females and 439 males from different educational centres in 5 different Spanish provinces: Valencia, Álava, Las Palmas de Gran Canaria, Teruel and Cuenca. Four hundred sixty-one of the students had completed the last year of primary education (12 years old), and 413 were doing their last year of compulsory education (16 years old).

Results

The results obtained are presented below:

- Section B: Spanish students do not include the environment in their idea of health.
- Section C: There are scarce problems pointed out including the relationship between the health of the environment and human health (Fig. 1). 40% of students do not mention any problem on environmental health. There is a predominance of problems derived from air and water pollution (33.14% of students). The rest of the environmental problems considered (disasters and consumerism) are mentioned in a much smaller percentage.
- Section D: Regarding air and water *pollution*, students demonstrate the highest degree of competence with great internal coherence and balance between knowledge, skills and attitudes. They perceive it as the biggest current environmental problem. Concerning *climate change*, they demonstrate poor skills, confusing issues of the ozone layer and global warming, and they tend to believe that all acts harmful to the environment cause climate change. They demonstrate good competences considering *hunger*, although the attitudinal dimension of solidarity prevails. Students show high sensitivity to personal problems, although they do not know how to solve them or the causes that explain their appearance. The poorest and most unstable competences are acquired when addressing *consumerism*, with no balanced relationship between their knowledge, skills and attitudes. When focusing on *allergies*, their skills are also scarce and unstable, with little internal coherence. In all cases, there is an increase in competences when going from primary to secondary education.
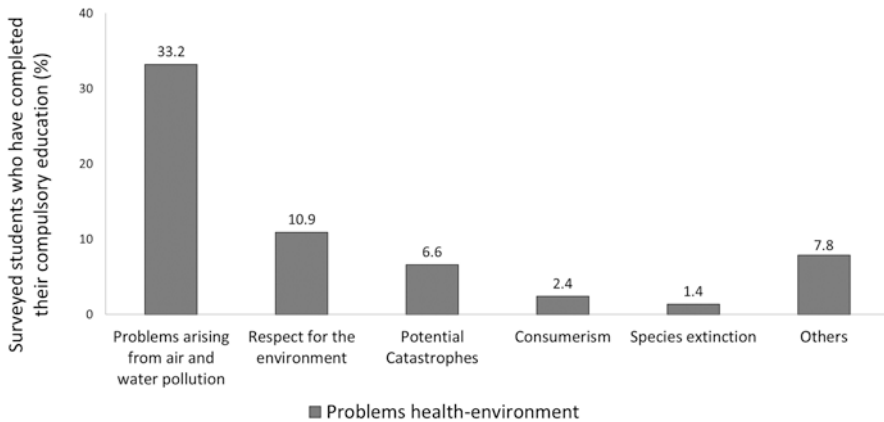
Fig. 1 Percentage of students who identify environmental health problems

Conclusions

In general, students have not acquired an idea of global, inclusive and holistic health, remaining in individualist positions and not integrating the environment into their own health. Their idea of the environment excludes people, which implies that they do not consider environmental problems as our own and they downplay the influence of the environment on our health. They acquire acceptable competences on pollution problems, few on climate change and hunger and almost none on consumerism and allergies.

Assessing the Complexity of Sustainability

S. Sprenger
J. C. Benninghaus
K. Kremer

This work uses the definition of sustainability presented in the Brundtland Report (World Commission on Environment and Development 1987). This definition calls for a sustainable lifestyle that is referred to in the widely cited sentence: "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (p. 54). Here we find the two principles of sustainability. One is the equity between generations and can be designated as intergenerational equity (Glotzbach and Baumgärtner 2009; Haughton 1999). The other principle pertains to the current generation that lives in different regions and at different levels of development. In this context, one speaks of intragenerational equity (Glotzbach and Baumgärtner 2009; Haughton 1999). Furthermore, the quotation cited above also includes the three typically used

dimensions or layers of sustainable development (Sadler 1990): environmental integrity, economic viability and a just society (Herremans and Reid 2002; Pufé 2012).

Sustainable development is only given if all three dimensions are integrated and if their particular requirements are fulfilled (Pufé 2012). It is evident that the interconnections of the principles and dimensions are complex. Students need to be educated to act in a sustainable way and thus need to be able to tackle complexity. This leads to the need to think about new ways of teaching complex issues and assessing how students already understand them. It should be based on a systemic approach (Rieß and Mischo 2010).

To address this need, Schuler et al. (2017) developed the model of systems thinking, and Mehren et al. (2017) modelled geographical system competence. The authors state that system competence highly correlates with content knowledge. Consequently, any assessment of students' skills to tackle complex issues needs a pre-examination of the students' conception on the concerned issue. In this contribution, we present both an assessment of students' conception of the content of global water consumption and an assessment of this complex issue with the mystery method (Leat 1998).

Study One: Conceptions on Global Water Consumption

To date, the field of research on students' preconceptions of sustainable development has not been comprehensively investigated. So far, only isolated studies are available. The present study addresses these aspects and raises, among others, the following question:

Which conceptions of sustainable development and virtual water do high school students hold (more information about virtual water: www.waterfootprint.org)?

A survey was conducted with 4 gymnasium (academic high school) classes in Germany: 102 students, 51 at secondary school and 51 at higher secondary school level. The questionnaire contained six items. Open task formats were used in three items. Responses were evaluated using the qualitative content analysis technique presented by Mayring (2014) and his online tool QCAmap (https://www.qcamap.org/).

In summary, we can say that most students see sustainability with an ecological and intergenerational focus. Only few made references to the economy, society or intragenerationality. Concerning the concept of virtual water, the vast majority did not have a concept of this construct. We saw references to digital media, which is common to this topic (Fremerey et al. 2014). All results can be reviewed in Benninghaus et al. (2017).

Study Two: Assessing Reasoning about Complexity

The mystery method was designed to let students create influence diagrams about systems (Leat 1998). The students receive several information cards with facts for connecting them to a diagram. We used the method to let students discover the causes and effects of virtual water consumption based on the study stated above. It is evident that the diagrams are different with every student based on the complexity of the issue. Consequently, assessment is difficult, because complex issues refuse to give single solutions (Fensham 2012). This is unfortunate because the diagrams promise to be an externalisation of the students' reasoning about the causes and effects of this complex issue, as we know from concept mapping (Novak and Gowin 1984).

Based on this, we created a reference that can be used for assessment. As a well-established method, expert concept mapping (Chi et al. 1982) was optimised. Since experts produce different diagrams while working with the mystery method, we adapted the method. We used relatedness judgements (Trumpower et al. 2010) and only asked every expert if two single information cards from the mystery method were connected based on the cause-effect principle. We counted how often each of the 16 cards was connected to one another.

Eight science teachers, sustainability scientists and science teacher students in the master's programme were selected as experts. It was shown that not all connections were chosen equally. The highest rating involved ecological facts, whereas facts concerning the other dimensions were networked less strongly. Figure 2 con-
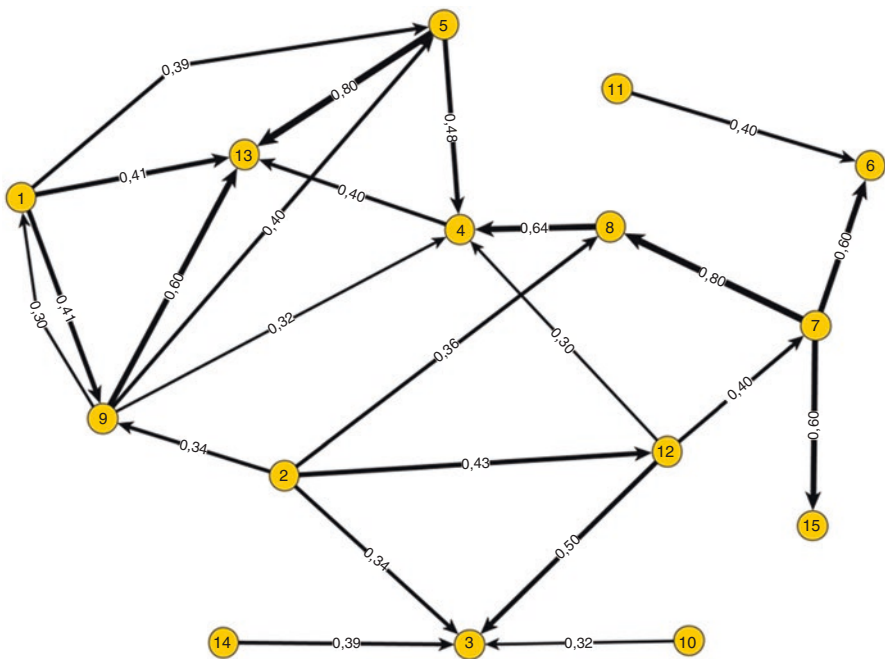

Fig. 2 Weighted connections (for major connections)

tains a weighted graph which shows all connections made by at least five experts and also shows how many experts chose the connections. We can see that there are few high-rated connections and more less-rated ones. This graph can now be used as a reference to assess students' ability to analyse this complex issue.

Conclusion

Based on the findings of the two studies we can summarise that dealing with complexity in class is challenging. Not only does students' content knowledge needs to be improved, but also it is a challenge to assess knowledge. We have attempted to provide some preliminary guidelines how to proceed.

Preparing for Complex STSEH Pedagogy

This study is based on Teacher Professional Development Programmes (TPDs) conducted within the EU-financed project PARRISE (FP7; grant agreement 612438). In PARRISE, 18 universities from 11 countries cooperated during the years 2014–2017. The overarching context of PARRISE was socio-scientific inquiry-based learning (SSIBL) (Levinson and The PARRISE Consortium 2017). SSIBL addresses the complexity of teaching science in an area embracing innovative and expanding projects and uncertain knowledge implementations to Science-Technology-Society-Environment (STSE) (Pedretti and Nazir 2011). In this context, we here have added an "H" to STSE for health, i.e. STSEH.

The SSIBL approach is characterised by the complexity of STSEH relations, knowledge uncertainties, fast development and disagreements due to different ethical issues. The SSIBL framework was used in the PARRISE project to try out different examples of TPDs addressing those issues in different cultural contexts. The TPDs focused on the recognition that there are diverse ways of negotiating socio-scientific issues which depend on the evidence available; the personal, political and social consequences of decisions; and the views of different actors in society (Levinson and The PARRISE Consortium 2017). Democratic citizens able to engage in socio-scientific inquiry and debate are needed to "build a scientifically literate society, which enables its citizens to participate in the research and innovation process" (http://www.parrise. eu/about-parrise/; 2017-01-17), and education has an important role in this.

The SSIBL framework emphasises that there are many diverse actors, stakeholders and perspectives and, consequently, many different orientations of STSEH education. SSIBL is based on three approaches, often independently pursued in schools: inquiry-based science education, socio-scientific issues (SSI) and citizenship education. The overall umbrella is responsible research and innovation (Lundström et al. 2017). The chosen theme of the Swedish TPDs at Malmö University with pre-service upper secondary general science teachers was nanotechnology. While nanotechnology offers new products which can benefit many,

there are also many possible risks both to human health and the environment. Therefore, it is an example of a complex SSI, characterised by risk, uncertainty, ignorance and indeterminacy but also by possibilities (Fensham 2012). During the last decade, quite a lot of research has been performed focusing on nanotechnology in relation to teaching and learning (e.g. Jones et al. 2013; Winkelmann and Bhushan 2016), but not much has focused also on the risks (e.g. Simonneaux et al. 2013).

This study investigates the teacher identity of pre-service science teachers after the TPD and their thoughts about implications for their coming teaching practice. Recently, Sjöström and Eilks (2018) suggested a Vision III of scientific literacy which emphasises critical global citizenship, political perspectives and philosophical values. They connected it to ideas of "reflexive *Bildung*", which can be seen as a late/post-modern version of *Bildung*. The philosophy of this orientation can be characterised with the following terms: scepticism, post-positivism, reconstructionism, embodied science, relationalism and eco-reflexivity (Sjöström 2018). The pre-service teachers' comments about nanotechnology in relation to teaching were analysed from late/post-modern perspectives in accordance with Vision III and "reflexive *Bildung*".

The TPDs with the pre-service teachers were held during the spring of both 2016 and 2017. Each TPD had 20 hours of face-to-face meetings plus a group project. After the TPD was completed, 5 + 4 student teachers were interviewed in groups. The TPD started with an introduction to the research field. This was done by introducing researchers from the nanotechnology field representing different views. One professor was engaged in development and implementation perspectives (through a podcast) and the other researcher from risk perspectives (lecture). This was complemented with literature that focused on these two perspectives. The pre-service teachers worked in groups. They were asked to choose a product from the market that included nanoparticles and work out a life cycle analysis for it. In the assignment, the pre-service teachers were supposed to make a societal conflict analysis, identifying different actors' interests in products from nanotechnology (i.e. social, economic and environmental dimensions). Furthermore, their project report had to include a lesson plan with pros and cons when teaching about nanotechnology in their future classrooms.

After the TPD, the interviewed pre-service teachers expressed how this project expanded their view of teaching complex issues related to SSIs and science in the making. In the analyses, two main themes emerged among the student teachers' view. The first theme was about authenticity and "real-world" issues. One student teacher said, "I think it is extremely important to include society in education. […] It helps to make it real, and that you learn something that is useful outside school". They emphasised the importance of not only science content but also other knowledge and perspectives. The other main theme the teacher students expressed was a changed teacher-student relationship. Due to the frontier character of nanotechnology, the teachers have to learn with the students: "You create something together with the students".

As a result of the TPD, the knowledge uncertainties of post-academic science also became noticeable. One student teacher said, "There is not only one truth, but different kinds of truth, depending on how you look at it", and another student teacher said "It gives you an insight that it is much more complex than you thought initially". They also mentioned the interplay between different actors, with different values and interests: "I think it was really exciting to get an overall picture of how it works between researchers, investors, businesses, politicians. It is the interactions that it are important to have knowledge about".

Previous studies have shown that teachers and pre-service science teachers often have problems with identity and ideology in relation to science teaching driven by STSE(H) (Hasslöf et al. 2016; Pedretti et al., 2008). This study showed that a TPD on nanotechnology, performed in the reported way, makes the pre-service teachers aware of the complexity and dilemmas of STSEH pedagogy. The difficulties of being a "neutral teacher" when opposite views cannot be verified by fact-based knowledge were brought up. This was considered challenging but also desirable and developing for science education. However, the pre-service teachers were also humble and reflective in relation to the complex teacher role and thought that science teacher education should include even more discussions about ethical-political dilemmas.

Discussion

The studies presented here underscore the importance and the challenge of introducing complexity into science education. The topics addressed all involve pressing societal issues pertaining to public health, the environment and sustainability (e.g. growing prevalence of diabetes, addressed by Arnold; concerns about long-term effects of nanotechnology, addressed by Sjöström et al.; sustainability of water resources, addressed by Sprenger et al.; environmental health, addressed by Álvaro et al.). The works demonstrate that, across locales, there is room for improvement in both students' understanding of these issues and teachers' readiness to teach them. The symposium discussion focused on developing effective strategies for bringing complex issues into the science classroom.

Participants in the discussion pointed out the potential controversy around the prerequisites for introducing complex science topics to children and adolescents. Little research exists into optimal sequences of ordered and complex issues, instructional strategies and the level of mathematical skills necessary for understanding complex systems described by non-linear relationships.

Truly appreciating the role of complexity in science is likely to raise citizens who understand the delicate relation between predictability and uncertainty in living systems. Indeed, mechanisms in ordered systems are systematic, i.e. they can be reproduced under any circumstances and always entail the same, predicted results. Complex systems, however, produce ephemeral mechanisms, i.e. in different

contexts they produce different, sometimes completely unexpected, results (e.g. Glennan 2010).

For example, somebody may, though fully ignoring nutritional guidelines throughout her life (see *Arnold* in this paper), never acquire type 2 diabetes, even if they have a family history of it. Conversely, nanotechnology may prove to be safe in every single epidemiologic study (see *Sjöström* et al. in this paper) and, nevertheless, may cause serious illness in certain contexts.

However, despite these cases, it still makes sense to teach about healthy diets and other strategies to prevent diabetes, particularly for students with type 2 diabetes in their family history. Conversely, it is probably not wise for teachers to warn against nanotechnology generally and context independently and thus cause fear or even panic in their students. But they may also want to abstain from trivialising the risk and uncertainty of such technologies.

In such, sometimes highly confusing situations, (linear) statistics are of limited help because the law of large numbers does not hold here. Understanding complexity and the non-linearity of biological systems can then provide a shield against intellectual shortcuts such as the *Churchill effect* described in the introduction.

Symposium participants and attendants felt that much attention needs to be given to teacher preparation for teaching complexity. Teachers themselves often have limited experience with complex topics, and, consequently, as illustrated by Sjöström et al. in this paper, while appreciating their importance, they may not be comfortable introducing them. Moreover, because such topics currently take up little instructional space, there are few instructional resources that would provide teacher support. Lastly, as evidenced by Sjöström et al. in this paper, introducing complexity changes the nature of classroom interaction and the teacher-student relationship. Pre-service and in-service teacher education should aid teachers in preparing for this changed relationship.

Conclusion

One student's comment in Sjöström et al.'s study that "there is not only one truth, but different kinds of truth, depending on how you look at it" is a persistent core motif in all four presented studies. If one was to symbolise this motif graphically, Fig. 2 in Sprenger et al. would certainly be a good choice. In fact, given a set of mystery cards and interactions, even experts draw various pictures that sometimes match only vaguely. As discussed above, this is a real challenge to most educational settings, which normally rely on certainties and epistemological games of truth. No wonder Swedish pre-service teachers are uneasy with this situation, and Spanish students feel overwhelmed by the complexity of environmental health questions.

Could here *adaptive staging* be of help (see section "Don't predict, adapt")? What does the slogan "Don't predict, adapt!" signify in such contexts? Questions we cannot yet answer adequately. The *Cynefin framework* (see section "The Cynefin framework") describes adaptive staging as *probe*, *sense* and *respond* (Snowden

et al. 2012). In simple systems, full prediction is guaranteed by the classification of initial states. In complicated systems, the same can be achieved by systematic analysis. In complex systems, however, each dynamically unfolding situation has to be staged (in the sense of probing) on a regular basis. Strategies have then to be adapted continuously, according to the evaluation results.

How can this approach be transferred to science education? We don't know yet. The findings presented in this chapter may be a starting point for developing new educational strategies that help students and teachers to cope with the challenges of complexity in Science|Environment|Health contexts.

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Promoting Students' Critical and Active Engagement in Socio-scientific Problems: Inter-Trans-national Perspectives

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Introduction

There appear to be many serious harms for individuals, societies and environments associated with fields of science and technology. Arguably of most concern is devastating climate change from burning of fossil fuels, but health harms (e.g. cancer) from

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consumer products like cigarettes, pesticides, household cleansers, nuclear radiation and food additives are among other problems. Although reasons for such harms are complex and uncertain, many scholars point to influences of powerful individuals (e.g. financiers) and organizations (e.g. transnational corporations) in orchestration of myriad living (e.g. think tanks; banks; trade organizations; universities; governments; engineers; etc.), nonliving (e.g. computer systems; transportation networks; weapons; etc.) and symbolic (e.g. competitiveness; socially responsible; sexy; etc.) entities into networks supporting their causes (Ball 2012; McMurtry 2015; Mirowski 2011; Pierce 2013; Ziman 2000). Approximately paralleling harms like those above appear to be dramatic global wealth concentrations by relatively few individuals and companies at expense of well-being of most other entities (Stiglitz 2016).

Given that many problems have some association with fields of science and technology, it follows that school science approaches are needed for encouraging and enabling students to critically evaluate relationships among fields of science and technology and societies and environments ('STSE') and develop and implement action plans to address perceived harms (Hodson 2011). In this chapter, we describe and analyse one such approach, that is, 'STEPWISE' (Science and Technology Education Promoting Wellbeing for Individuals, Societies and Environments). This is a framework developed in 2006 by Larry Bencze that, as elaborated in Fig. 1, organizes science education learning goals (e.g. Skills, Products and STSE education) into a tetrahedron to encourage and enable students to altruistically 'spend' at least some of their cultural and social capital—e.g. as attitudes, skills and knowledge ('ASK')—on *self-directing* research-informed and negotiated action (RiNA) projects to address harms they perceive in STSE relationships. Emphases on student direction largely assume that deeper and more committed learning may occur when learners have direct controls over translations between phenomena of the world (e.g. weather, climate, etc.) and representations (e.g. graphs of temperature variations, climate change concerns, etc.) of them (Wenger 1998).

Mainly because students have not often had sufficient experiences with many aspects of RiNA projects, the schema in the lower right of Fig. 1 was developed to provide them with relatively teacher-led 'apprenticeship' lessons and activities to help them develop expertise, confidence and motivation for eventually self-directing such projects. Starting with student reflections on their existing conceptions, attitudes, etc., this constructivism-informed schema then encourages teachers to teach students some often difficult-to-discover facts, ideologies, etc. associated with science and technology before asking them to practice some small-scale RiNA projects (receiving help, when requested). Depending on numerous factors, including students' ages and stages of development, resource availability, etc., students may require more than one set of apprenticeship lessons and activities, often providing them with increasingly more complex ASK (e.g. about actor-network theory) that they may use in RiNA projects.

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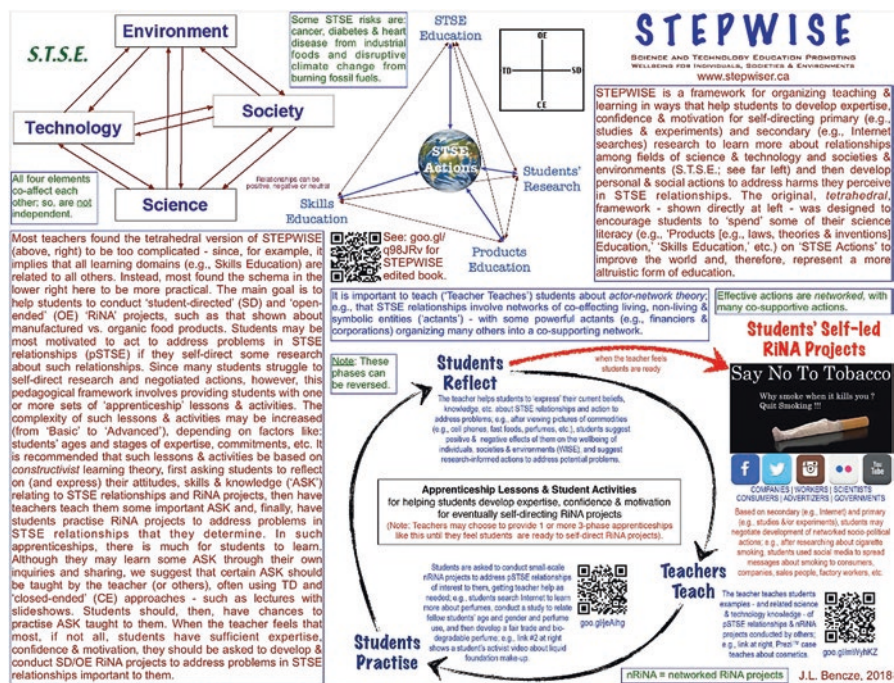e-mail: mattheww@uw.edu

Fig. 1 Summary of STEPWISE frameworks

Since the development of the STEPWISE frameworks, considerable qualitative educational action research has been conducted in primary, secondary and tertiary science education contexts to learn more about their effectiveness. Such research suggests, firstly, that STEPWISE-informed approaches can be helpful in promoting self-directed RiNA projects—several examples of which are provided in two special issues of the journal *JASTE* (goo.gl/N00b3s; bit.ly/2JGIgtf) and in an edited book (Bencze 2017 [goo.gl/q98JRv]) featuring teachers' documentary reports of their relevant teaching/learning experiences. A brief summary[1] of some major findings from research involving one teacher (drawing from 6 of 17 *documentary* chapters in the book) also is provided in the next section of this chapter. This is followed by a section featuring summaries[2] of 5 of the 33 *analyses* chapters in the STEPWISE-edited book. Authors of these latter chapters were asked to analyse and evaluate STEPWISE frameworks and, where appropriate, discuss similar approaches in their work or suggest alternatives to them. We finish with an overall summary and conclusions section, coedited by all authors here.

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[1] This summary was written by Larry Bencze and Mirjan Krstovic, with all other authors providing editorial support.

[2] In order, these five summaries were written by Lyn Carter and Jenny Martin, Audrey Groleau and Chantal Pouliot, Ralph Levinson, Isabel Martins and Matthew Weinstein. Again, all authors here contributed to editing of these sections.

Some Action Research Findings in Uses of STEPWISE Frameworks

Action research involving graduate students and/or Larry Bencze facilitating and learning from educators' efforts to develop and implement STEPWISE-informed pedagogical approaches appeared to help generate some relatively reliable claims about promotion of student-led RiNA projects. Many such findings are discussed in the STEPWISE book (Bencze 2017), but the schematic in Fig. 2 also may be helpful to readers. This schematic depicts RiNA projects as involving reciprocal translations between phenomena of the 'world' and representations ('signs') of them. In both directions, there may be inefficiencies in translations. Ontological gaps (inefficiencies) seem likely to occur because of differences in composition of two entities involved (e.g. a tree vs. a photograph of a tree) (Roth 2001). Such limits in translation suggest that we must associate some uncertainty with all RiNA projects. Inefficiencies in translations may, however, also have some intentionality known as ideological gaps (Bencze and Carter 2015)—when, for example, researchers purposely draw graphs ('signs') in ways that may overemphasize a cause-effect relationship. In terms of the schema in Fig. 2, several suggestions (in rectangles) for promotion of self-directed RiNA projects emerged from educational research.

Among many recommendations—such as those noted in Fig. 2—for uses of the STEPWISE framework that emerged from research, particularly important findings
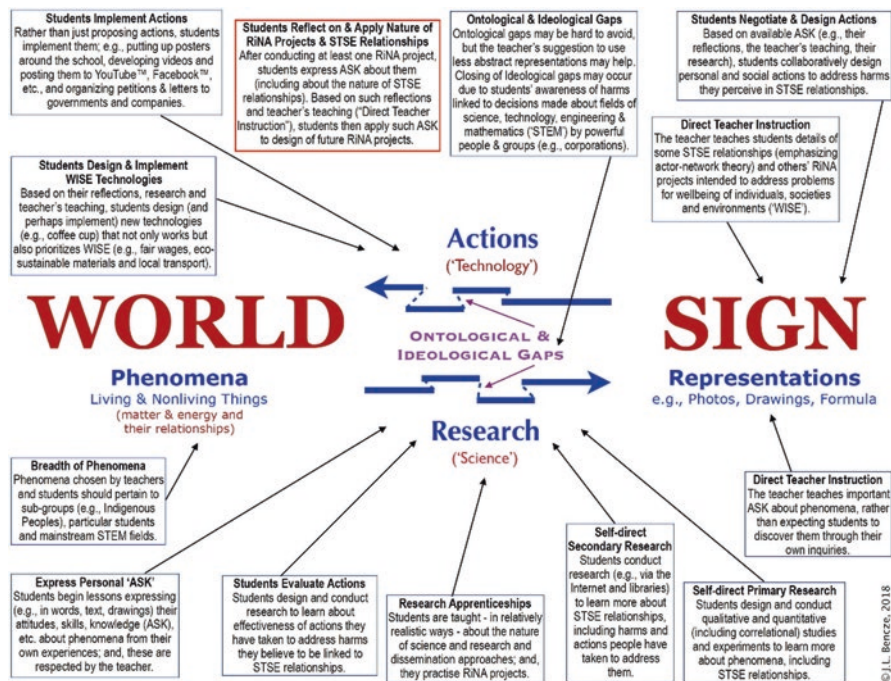

Fig. 2 Summary of findings from STEPWISE-informed action research

seemed to involve benefits of students' uses of aspects of actor-network theory (ANT) (Latour 2005). To teach students about ANT, a secondary school science teacher (Mirjan Krstovic) conducted—for example—a Socratic lesson in which the class developed an actor-network map of cell phones, with special focus on concepts of punctualization (i.e. making a phone seem to be an isolated entity) and de-punctualization (e.g. exposing networks of actants, such as transnational trade organizations to which the phone may be connected but often are not obvious to people) (Callon 1991). Students also were shown The Story of Stuff videos (storyofstuff.org/movies/) and asked to discuss actants (e.g. allusions to 'sexiness') that may encourage product consumption while distracting consumers from awareness of possibly harmful actants (e.g. microplastics in liquid detergents and shampoos).

After such lessons, students were then asked to self-direct RiNA projects to investigate and address harms they identified with particular consumer products. One such student project is summarized in Fig. 3. Students' secondary and primary research (phenomena → representations) generated, respectively, findings such as the actor-network depiction of material-semiotic relationships involving batteries and the graph of students' inclinations to purchase educational board games. Based on findings, students then developed a 'Battery Jeopardy' board game, which prioritized statements promoting social justice and environmental sustainability (representations → phenomena).
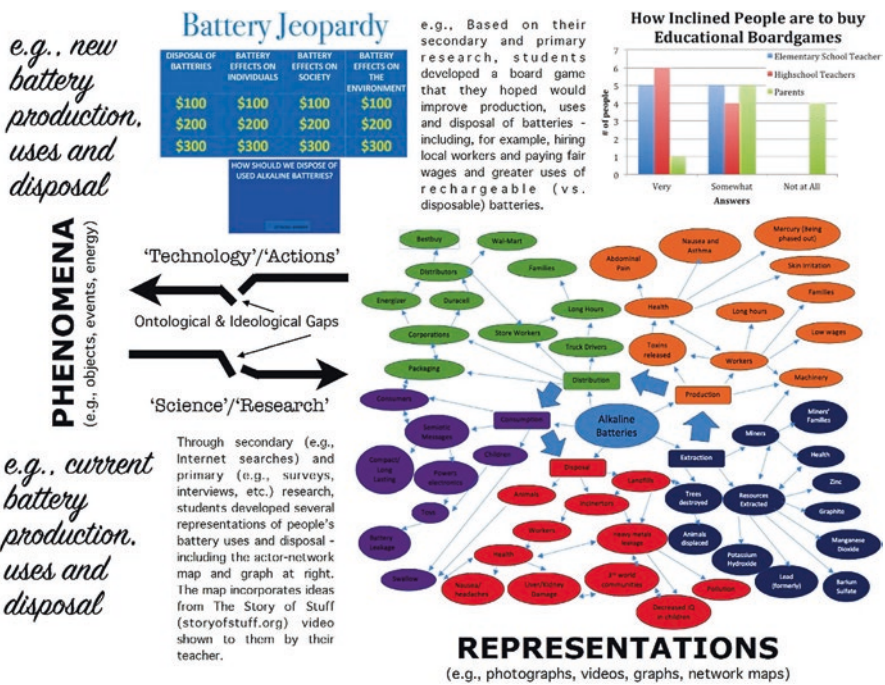

Fig. 3 Summary of findings from students' RiNA project

Although research suggested that STEPWISE-informed pedagogical approaches could help many students to develop expertise, confidence and motivation for self-directing innovative and possibly effective RiNA projects, it also became clear that such teaching and learning may be largely confined to relatively rare contexts featuring a supportive *dispositif* (Foucault 2008)—that is, a network of largely cooperating living, nonliving and semiotic actants. It seemed, for instance, that Mirjan Krstovic was able to successfully implement much of STEPWISE because, for instance, STSE education was listed first among three curricular goals (MoE 2008), his school's principal and department colleagues supported educational exploration and innovation and Mirjan (after graduate school education) supported relatively naturalist-antirealist conceptions (e.g. science inquiry may be adversely influenced by private funding) of nature of science (Loving 1991).

Theoretical Analyses and Applications of STEPWISE

Towards the end of about a decade of field testing of the theoretical (tetrahedral) and pedagogical (more linear) STEPWISE frameworks (Fig. 1), several science education scholars from around the world were invited to contribute chapters to the STEPWISE book (Bencze 2017)—asking them to evaluate the frameworks and, if relevant, to discuss ways they may relate to their work. To provide readers with a sense of such analyses, summaries of five such chapters are provided in the next section. Authors chosen to write these summaries have been collaborating with Larry Bencze for at least 5 years and share several perspectives about societies and science education. The sequence of summaries provided below is given in alphabetical order of the first author in each case.

'I Had to Take Action Straight Away': Preservice Teachers' Accounts of Pro-environmental Action

STEPWISE is a framework for science education that encourages students to work towards a better world utilizing, in part, their understanding of science and technology. Lyn Carter and Jenny Martin developed a programme that focuses on actions that are at the heart of the STEPWISE framework, employing a discursive psychological perspective to investigate preservice teachers' sense of responsibility for education for sustainability (EfS) or pro-environmental action. Unlike more frequently invoked cognitive psychology, discursive approaches acknowledge cultural and relational aspects of any action in the social world, and no distinction is made between social and psychological phenomena. Such a unique approach holds implications for EfS studies, STEPWISE and other socio-political and STSE projects self-reflecting about cognitive psychological assumptions that depict individual minds and knowledge as separated from their social realization. If socio-cultural

science education is to be authentic, then schisms between cognitive approaches and the social world need to be acknowledged.

Research described here involved about 400 first-year Bachelor of Education preservice elementary school teachers at an Australian university. The science course's topic area, environmental sustainability, its focus on action and an open inquiry pedagogy involving both primary and secondary research ensure it fits within STEPWISE. Instructors aimed to empower preservice teachers to position themselves as pro-environmentally active, both in their lives and in their teaching. Preservice teachers' reflective accounts of their 'Eco Challenge', a project in which they undertook an evidence-based appraisal of their current sustainability practices before implementing alternative practices to reduce their ecological footprint regarding food and energy consumption and production of waste, were analysed. The preservice teachers recorded their progress in an open-ended, reflective journal format they kept across the 12-week semester, providing evidence of their adopted practices evaluating and explaining their successes or otherwise as well as reflections upon their own or others' attitudes and information they researched that would elaborate their positions.

Discursive psychology (Harré 1984) acknowledges cultural and relational aspects of any action in the social world and requires an account of 'positioning' of the actor(s). A *position* is a person's psychological location in an ongoing 'conversation'. Social psychological phenomena are manifested as social acts. The analysis of social acts involves three mutually interdependent features of a conversation, the actual doings and sayings ('action'), the 'positioning' of actors and the conversational 'storylines' (Harré and van Langenhove 1999). Cognitive psychological approaches to science education research, by contrast, typically privilege generalized inner mental states when looking at (in our case here) preservice teachers' stated intentions or attributions of intention to students as central to operationalization of action. Rather than looking to what students say (or do) in a social setting as representing general psychological states (e.g. wanting), a discursive psychological approach, instead, looks to *functions* of students' *sayings or doings in their context of use* (Wood and Kroger 2000). Discourse-based approaches in science education research explore action in science as complex social activities, suggesting that action cannot be explained as individual intentions (as in cognitive psychology); rather, it needs to be understood as social meanings achieved in each intention and in terms of resultant social practices. This approach, which seems less usual in science education research, can avoid limitations posed by much of cognitive psychology at large in our field.

Research findings indicated that taking action was linked to individual intentionality and responsibility. This research supports claims made by Preston (2011) that young people tend to adopt ecological crises discourses where individual responsibility is uncritically taken as the cause of environmental problems. Preservice teachers' pro-environmental engagement was limited to individual action or 'small things', and they differentiated between instinctive and deliberate action. Rather than looking to action as meaningful in context, or how they were positioned in social contexts salient in their everyday lives (e.g. as non-empowered citizens), the

preservice teachers became entrapped in a loop of deliberation over attribution of individual intentionality, induced by their adoption of cognitive psychological constructs like 'motivation' and 'intention'. These findings suggest that the Eco Challenge elaborated a conservationist/resourcist approach to environmental education (Sauvé 2005), limiting students' critical engagement. This research informs work in promoting pro-environmental engagement with preservice teachers and suggests that opportunities for preservice teachers to position themselves as members of collectives in relation to current local and global socio-political contexts could be a way forward to broaden their concepts of action—a central aim of STEPWISE.

Preservice Teachers Discussing Social and Economic Disparities During a Discussion Game

Science education must not be blind to economic dimensions to which it contributes and by which it is influenced. This is the position expressed by the authors of the collective work entitled *Activist Science and Technology Education* (Bencze and Alsop 2014), which points to needs for deep-rooted change, 'tak[ing] more seriously wider social, political, economic and environmental contexts in which our practices reside and also seek to resist and influence' (Alsop and Bencze 2014, p. 2). In this section, Audrey Groleau and Chantal Pouliot present the group discussion game, *Decide*, illustrating that it shares several democratic values with STEPWISE frameworks.

Decide is a group discussion game that broadly shares STEPWISE orientations. It is distributed under a Creative Commons License (Attribution—ShareAlike 3.0 Unported), which means that it is highly accessible and shared free of charge in an altruistic spirit. The game's instructions give the players a great deal of leeway, both in terms of the form the discussion will take and its content. Decide invites players to discuss various issues/controversies that often are overlooked in science and technology education. For example, there are game cards that explicitly ask questions relating to uncertainties involved in pertinence of public engagement in these debates and in socio-political decision-making processes.

Decide is accessible on the Internet at www.playdecide.eu. It must be printed on paper or cardboard (it is not played online). While the recommended number of players is four to eight, we observed that sessions involving three or four players usually turned out to be the most productive and the most agreeable. Several versions of the game are available—in several different languages (e.g. French and Portuguese) and exploring various socio-technical controversies (e.g. orphan drugs, biomedical tests or climate change). There are more than 32 kits available in English. Each game session involves four phases. The *preparation* phase involves preparing the material (printing up the kit and cutting out the cards) and consulting the rules of the game, which are simple and quite flexible. The first phase of the game itself (the *information* phase) lasts approximately 30 min. Essentially, the players learn about the controversy by reading four possible policy positions on the controversy, as well as cards explaining some of the issues involved. The second phase of the

game invites the players to *discuss the controversy* (for approximately 30 min), either taking turns or choosing an open discussion format. During the third and last phase of the game, the players try to *formulate a shared group response* (this phase lasts approximately 20 min). The players reread the four policy positions presented during the information phase and can add others as they see fit. They then vote individually on all four policies. Lastly, they negotiate and attempt to find some common ground, without necessarily having to reach a consensus.

Decide is coherent with STEPWISE-informed approaches, as it provides opportunities to address well-being of individuals, societies and environments. One of the pertinent contributions of Decide to philosophical and pedagogical aims of STEPWISE certainly lies in opportunities it provides participants to discuss development of techno-science while considering, in the words of Larry Bencze and Lyn Carter (2011), that '[w]ealth and well-being are funneled towards traditional elites, typically at the expense of the vast majority of other people and to the detriment of living and non-living environments' (p. 650). Because it allows de-punctualization of nanotechnologies (Callon 1991), namely, identification of actor-networks that interact, Decide can be mobilized during the Teacher Teaches phase of the STEPWISE apprenticeship (Fig. 1). Decide could be used as a starting point to help students identify significant issues underlying a controversy, pinpoint those that interest them in particular and form an informed opinion about them. The students could then be asked to pursue their own investigations and engage in social action or to put together a game kit (as an 'action') on a current or local socio-technical controversy that interests them.

Socio-Scientific Inquiry-Based Learning: Taking Off from STEPWISE

In the European Union, educational policy-making bodies are encouraging projects of inquiry-based learning to stimulate interest of young people in science and broaden the science and technological base (Rocard 2007). A broader vehicle for attaining these aims is Responsible Research and Innovation (RRI), a means of public accountability for scientific and technological research *for* people and *with* people (Owen et al. 2012). Such proposals need to be treated with caution, however, particularly in light of dismantling of welfare state policies in Europe, rise of free marketism and entrepreneurship, as well as the complexity of relations of technical expertise and lay knowledge and concerns.

Promoting Attainment of Responsible Research and Innovation in Science Education (PARRISE) is a European-funded project that takes inspiration from STEPWISE (Bencze and Carter 2011) and reflects its purposes of social justice. Directed towards supporting teacher professional development, it incorporates socio-political questions as the object of its inquiry, critically addressing issues of consumerism and unequal distribution that affect contemporary neoliberal economies. Components of this model of inquiry draw on substantive scientific knowledge incorporating RRI, through Critical Citizenship Education, Socio-Scientific

Fig. 4 Model for socio-scientific inquiry-based learning

Issues (SSI) and Inquiry-Based Science Education (IBSE), hence the acronym SSIBL (Socio-Scientific Inquiry-Based Learning) (Levinson and PARRISE consortium 2017) (see Fig. 4).

Social values at the heart of this project recognize that we live in a diverse world where technological change should be underpinned by social justice and political responsibility. SSIBL prioritizes authentic questions that stem from students' concerns, leading to non-trivial actions that take into account social, political and cultural constraints and uncertainties. Inquiries reflect issues that have personal, social and global relevance. It has three principal components reflected in Fig. 5.

Asking personal/social/controversial questions relevant to socio-scientific issues of an authentic problem for which there is no clear solution. Examples for different age groups might involve students investigating consumerist and health claims for e-cigarettes, the best recipe to bake a birthday cake for a diabetic friend, finding out the best way to regulate temperatures in the school classroom. The inquiries should stem from concerns and preoccupations of the young participants, although scholars such as Humbel et al. (2012) recognize that social inquiries stimulated by controversy need to incorporate a pedagogical triggering mechanism, an 'élément déclencheur'. This might involve teachers using media text and images to prompt discussion or encouraging students to raise questions from a 'rights' forum. Hence, part of the SSIBL programme at the scaffolding stage has much in common with apprenticeship activities in STEPWISE.

Working towards *a solution* involves an inquiry-based approach (e.g. testing out predictions, evaluating data) by working with and for public and personal goods based on political knowledge and skills. SSIBL's inquiry-based approaches differ from school science inquiries. While they might involve experimentation, for example, in testing and reporting on various insulating materials to support temperature
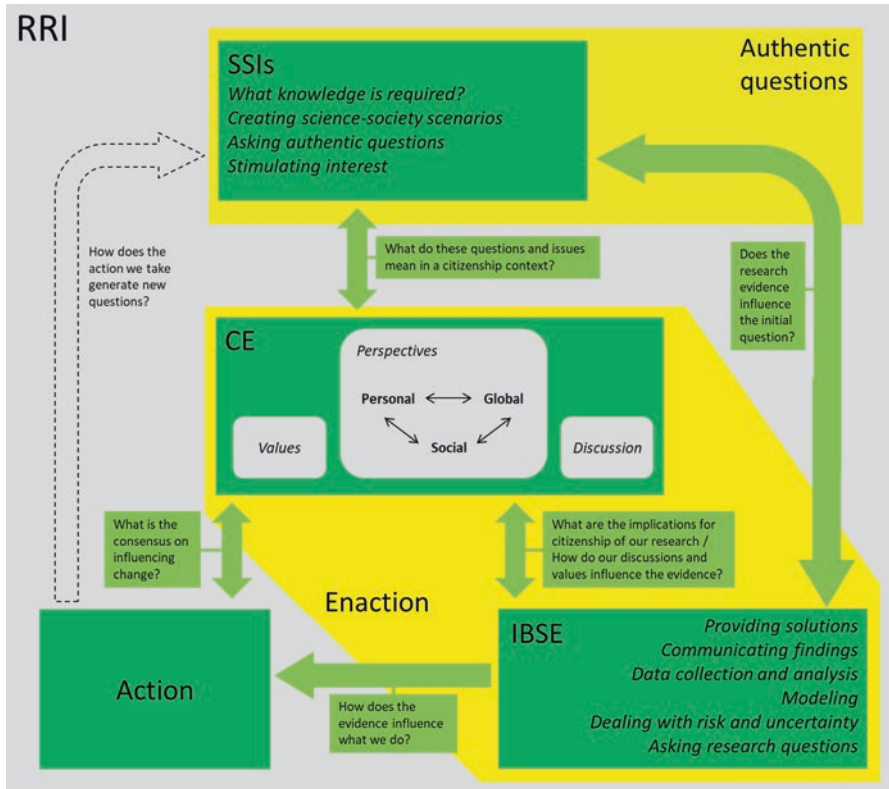
Fig. 5 Schema for socio-scientific inquiry-based learning

regulation in the school classroom, they might also involve carrying out social surveys as well as drawing on secondary data. For example, through research-informed action (RiA), Krstovic (2014) has supported high school students to raise awareness about powerful corporations using evidence-based research to produce videos, brochures and posters, to devise new labels for water bottles and to do class presentations to lobby for action. One feature of the RiA approach is the use of correlational studies, for example, the use of surveys to investigate relationships such as that between gender and use of cell phones.

Actions, arising from these solutions, may be of various kinds—ranging from active lobbying, addressing a social injustice to deepening a question and prompting further reflection. Action can be taken at various levels, from prompting new questions, stimulating further reflection to working with political authorities to help enact material and social change.

Overall, the SSIBL project within the PARRISE research and development programme appears to have led to some significant student outcomes using STEPWISE-informed principles in the context of prioritization of inquiry-based learning—an approach not recommended within the STEPWISE framework when predetermined conclusions are to be learned.

Interrogating STEPWISE Principles: Concepts of 'Well-Being'

STEPWISE has addressed issues concerning goals and aims of science education in terms of its potential to change and promote well-being of individuals, societies and environments. However, even a quick inspection at relevant literature reveals polysemy around the concept of well-being. Its related meanings, which refer to cognate concepts, such as quality of life, welfare, common good and social justice, invoke a few questionings: Is it possible to establish parameters in terms of which to describe what constitutes well-being for different individuals, societies and environments? Which would be the values to inform such choices? (and) How should one assess adequate levels in each case?

For the last few years, there has been a growing recognition that well-being should be considered a multidimensional concept (McGillivray 2007). We will find relevant insights about well-being in fields as diverse as Economics, Public Health and (Moral) Philosophy, all of them conceived against a background of influences that are of historical, cultural and social in nature. The complex interaction between such aspects explains problems of accounts which will, for instance, associate well-being with achieving a satisfactory balance of pleasure over pain or those that equate it to achievement of desire satisfaction. For instance, John Stuart Mill has challenged hedonist perspectives by pointing out the fact that not all pleasures can be considered equivalent. Contemporary scholars like Qizilbash (1998), using an example of a person who enjoys smoking but is unaware of its harmful effects, stressed the extent to which our desires can be affected by knowledge. Issues surrounding relationships between knowledge and well-being are particularly relevant for science educators interested in exploring socio-scientific issues. Take the example where individuals and societies have increasingly become dependent on technological artefacts, like mobile phones. The awareness that mobile phone production is possible at the expense of child labour and environmental damage may not be sufficient to stop us consuming these goods. Complexity of networks of interests and practices is evident when we face the irony that these very products of exploitation provide us with opportunities, such as through social media activism, to collectively engage in denouncing and campaigning against unacceptable conditions under which they are produced.

Within this perspective, well-being seems to be an aspect of political life, linked to participation and decision-making in the context of some actual experiences of enacting the STEPWISE framework, as described in Bencze (2017). As such, it involves contradictions but also ambivalences, and, in order to analyse those, we need a theoretical-methodological framework that is apt to consider how complex and mutable are sets of power relations that shape production, enactment and consumption of science education discourses. Critical discourse analysis is suggested as an apt framework to do so, in so far as it explores dialectical pairs, such as structure/agency, colonization/appropriation and reflexivity/ideology (Chouliaraki and Fairclough 1998) in promoting articulations between local experiences and socio-historical dimensions. Views of well-being that address relationships between individuals and

social groups can be productively used to tease out aspects involved in discussions of roles of education in empowerment of individuals and emancipation of social groups for political action. The articulation of social theory and discourse, as present in critical discourse perspectives, is suggested as a powerful analytical tool to examine such connections as present in educational literature, multilateral documents and curriculum materials. The irreducible nature of relationships between discourse and society may also help foreground nuances in global accounts of ways through which (science) education has been recruited as a major component of a hegemonic project of society based on values of capital. In this way, one can seek to establish relationships between ways through which relevant aspects of *contemporaneity* (e.g. individualism, efficiency, competitiveness, space-time 'compression', technologization of social life, etc.) are represented in science education. We can question possibilities of promoting well-being outside practices defined by dialogue and co-responsibility on two grounds. One reason relates to risks of dismissing diversity and eliminating pluralism as an important element in construction of identities and as sources of reflection and alterity. Another reason would be undesirable reinforcement of asymmetry between academic/disciplinary and social/cultural contexts. Critical analysis of dialectical relationships in discourse also reveals how those who seek to promote well-being are impacted not just by reflexive dimensions of their actions but also by reconfigurations in social relations that can result in emancipation and in extended possibilities of participation and knowledge production of targeted groups.

Based upon that and in order to summarize, it is apparent that, in the context of the STEPWISE framework, well-being is best understood as a dialectical generative process rather than a stage to be reached once certain conditions are met. This would involve adopting a political philosophical outlook on well-being in order to problematize relationships between education and different models of socio-economic development in contemporary society.

Understanding Opportunities and Contradictions in the Grammars of Activism and Schooling

To a great extent, STEPWISE—like many schemas drawing from science and technology studies research—provides alternatives to neoliberal principles and practices. In the USA, 'STEM' (Science, Technology, Engineering and Mathematics) education appears to act as a Trojan horse for a neoliberal re-articulation of science (Bencze et al. 2018). On the one hand, it validated science by its inclusion in the umbrella of the acronym, but, in practice, as evidenced by the US science education standards, science became infiltrated everywhere and, to some extent, suborned by other fields, most notably engineering. Engineering has to be read as *marketed science*, science built on competition and on technical fixes (rather than modelling and understanding) and science as product. In other words, the engineered science of standards such as the USA's Next-Generation Science Standards (NGSS) should be read as science that has lost its ethical autonomy from the market.

Furthermore, STEM education has to be understood as an exclusion of those fields not represented in its acronym, the arts, literature and, especially, the social sciences, which are explicitly marked as 'other' in the National Research Council's Framework (Committee on a Conceptual Framework for New K-12 Science Education Standards 2011), which provided guidance to the NGSS. Yet, such fields are not simply removed; they are segregated and limited in their impacts. Science and technology studies (STS), the traditional bridge between science, technology (cum engineering) and the social sciences, is relegated to the engineering portion of the NGSS standards, suggesting an ethical and political innocence to the sciences. Nowhere are the many instances of ethical abuses of subjects, the antidemocratic selection of research projects or the connections of science to empire permitted in the NGSS.

Comments above emphasize US contexts, but it should be clear that the move to STEM education, the move to standardization and the move to neoliberal practices at every level are part of a global process, one that Finnish educator Pasi Salhlberg (Sahlberg 2015; Strauss and Sahlberg 2012) mockingly calls GERM, *Global Educational Reform Movement*.

It is in the light of this political-economic-rearticulated matrix that we should, perhaps, consider STEPWISE. STEPWISE is the antithesis of the articulation suggested by the NGSS: it hybridizes science, technology, ethics and political economy to put wellness, rather than profit, at the centre of science education. At the level of theory, it does this through drawing on a materialist/realist version of actor-network theory (ANT). At the level of pedagogy, it does this by making student activist projects the culmination rather than 'inquiry' or 'knowledge' or even 'understanding', as the cognitive science school of science education would prefer. It is at extreme odds, therefore, with the *grammar* of US education, as it is now practiced both on the ground (which remains largely devoted to memorization) and even in the neoliberal ideal (NGSS's inquiry plus engineering design problems).

Where the NGSS is about commodification of science and each student—as the student is measured and then marketed, i.e. reduced to human capital—STEPWISE ideally is about decommodification of multiple actors/actants. Much of the work of students in STEPWISE is about taking actual commodities and 'unpacking' them: locating those products in webs of labour, environmental extraction and toxicity. Students (ideally) are themselves decommodified as they become agents of change and work towards transforming the world. Finally, the curriculum itself is decommodified as students craft their own projects outside of the standardized organization of schooling. We might say 'ideally' because of fears that extant schooling is more than flexible enough to compromise and transform even a counterreform like STEPWISE to fit in with the hierarchies, grading schemes, discipline regimes and age-graded structures that comprise what Tyack and Cuban (1995) call the grammar of schooling.

The situation may not be hopeless, however. Rather, the lesson needs to be that teachers have to engage in struggle themselves for wellness at the level of the nature of schooling. Teachers of STEPWISE have to be ready to both resist traditionalists and GERM reformers who would render such healing curriculum outlaw. In the USA, this has meant uniting forces with progressive unions (or progressive caucuses within unions) or more informal organizations such as the Badass Teachers

Association (the BATs), which has networked teachers apart from the union to stand against GERM reforms specifically. The BATs are hardly alone. National Opt-Out (which resists standardized testing) and Network for Public Education (Diane Ravitch's anti-GERM group) are two other organizations involved in this struggle.

By expanding STEPWISE to promote wellness in institutions of learning more self-consciously, as it does in the world at large, struggles over schools and struggles over knowledge (science) appear intimately tied (Apple 1982, 2014). Schools are a key site for production of legitimated knowledge, and, thus, to contest the nature of schooling is also to contest over the nature of science itself: Who should science serve? Whose knowledge counts? Whose problems matter (are made material)? Posing these questions, and coming back with democratic answers, may be STEPWISE's greater effect.

Summary and Conclusions

Although fields of science and technology appear to have generated much knowledge and many inventions that have been greatly valued by humans in various global contexts, we are concerned about harms for well-being of individuals, societies and environments that appear to stem from influences that powerful people (e.g. financiers) and organizations (e.g. transnational corporations, governments and nongovernmental organizations) have over fields of science and technology and over many or most other living, nonliving and symbolic entities around the world. In light of our view that governments, like so many other entities, have been assimilated into a global network—not unlike *The Borg* in the Star Trek™ entertainment series—largely controlled by procapitalist people and organizations, it seems clear to us that science educators and others must prioritize education of students about harms linked to such power relations and to prepare them to develop and implement personal and social research-informed and negotiated actions to try to address harms important to them. This chapter has provided descriptions and examples of, and justification for, a general pedagogical framework ('STEPWISE') that appears to promote such active public engagement. It also has provided summaries of congruent pedagogical approaches, such as the Decide game, Socio-Scientific Inquiry-Based Learning and Eco Challenge, used in other parts of the world (e.g. Québec within Canada, Europe and the UK and in Australia, respectively). Outcomes of such approaches are promising in terms of potential for improvements in social justice and environmental well-being.

STEPWISE pedagogy and related strategies/schema should not, of course, be considered panaceas for what ails science education as it relates to well-being of individuals, societies and environments. All forms of education are, of course, highly contextual and, therefore, needing myriad and unpredictable pedagogical approaches. Moreover, all education is undoubtedly biased and, related to that, potentially disempowering for some other individuals and groups. Indeed, authors featured in this chapter advise caution, for instance, in conceiving of 'well-being'

and 'activism'—core aspects of STEPWISE. At the same time, at least one author here has cautioned that many benefits attributed to STEPWISE may be inhibited by large-scale educational movements like 'STEM' education that appear to prioritize economic market goals over general societal and environmental well-being. With such caveats and barriers in mind, therefore, although we may feel that learning outcomes and pedagogy provided here may be liberating and invigorating for individuals, societies and environments, it seems necessary to continually collaborate with numerous—and often diverse and oppositional—stakeholders to democratically codevelop perspectives and practices (McLaren 2000).

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Understandings of Scientific Inquiry: An International Collaborative Investigation of Grade Seven Students

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Introduction

Scientific inquiry (SI) has been a perennial focus of science education for the past century, and it generally refers to the combination of general science process skills with traditional science content, creativity, and critical thinking to develop scientific knowledge (Lederman 2010). Recent reform documents have emphasized that students should develop the abilities necessary to do inquiry and/or science practices as well as have an understanding about inquiry (e.g., ACARA 2015; Brazil 1998; Benchmarks for Science Literacy, AAAS 1993; A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas, Ministry of Education, Pedagogical Secretariat 2018; National Research Council [NRC] 2011). The National Science Education Standards (NRC 2000) were explicit in their differentiation between the abilities to do inquiry and knowledge about SI. This distinction also continues to be evident in the Next Generation Science Standards (NGSS 2013). Although the NGSS refers to science practices as opposed to inquiry, the NGSS considers "practices" as extending well beyond simply being involved in science processes. In either case, "inquiry" or "practices" refer to engagement of students in behaviors similar to those of scientists. Similar distinctions are becoming more prominent in reform documents throughout the world. Quite simply, it seems logical that students will improve their ability to do inquiry/practices if they have an understanding about what they are doing and this knowledge, combined with knowledge of science, will enable students to make more informed decisions about

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scientifically based personal and societal decisions. The position here is not that the doing of science is unimportant. It is important for students to be engaged in inquiry practices. Indeed, these experiences provide the best instructional platform for students to reflect back upon how scientific knowledge is developed.

Research indicates that, much like the research on understandings of Nature of Science (NOS), neither teachers nor students typically hold informed views of SI (Lederman and Lederman 2004; Schwartz et al. 2002). The research base for SI is markedly smaller than that for NOS. This small research base is partly due to both the conflation of NOS and SI and the lack of a readily available, or frequently utilized, instrument similar in nature to the various forms of the Views of Nature of Science questionnaires (VNOS; Lederman et al. 2002). Now with the development of the VASI, the research base for SI can begin to grow. There are those that have concerns with instruments that purport to assess students' understandings about constructs such as inquiry and NOS (Hammer and Elby 2009; Hammer et al. 2005). Their arguments primarily revolve around the idea that context impacts students' abilities to express what they understand about NOS, and this has been extended to inquiry. The results of this investigation show otherwise as the VASI clearly provides students with a variety of contexts within which to express what they understand about inquiry. Additionally, prior research also would call in question the claims made by Hammer and colleagues (Bartels and Lederman 2017; among others).

While SI is inextricably linked with NOS, what is notable is the lack of a robust research base centered on students' understandings about inquiry. What is evident is the preponderance of research focused on the doing of inquiry, which oftentimes is assumed to necessarily lead to an understanding of inquiry. The belief that doing inquiry is a sufficient condition for developing understandings about SI, unfortunately, is a misconception (e.g., see Wong and Hodson 2009, 2010). In order for students to fully understand, aspects of SI (which can be done in conjunction with conducting SI but not necessarily) need to be intentionally taught.

The intent of this collaborative project was to report on students' understandings of SI across the globe with a valid and reliable assessment tool; we can begin to see what students of the same grade levels know about SI in various countries/regions. The purpose is not to focus on comparisons across countries (especially since instruction, curricula, and cultures vary widely across nations), but rather to develop a baseline of understandings worldwide. Readers are urged to resist the temptation to compare the findings from their country/regions with the findings from the other countries/regions.

Why Should Students Understand Scientific Inquiry and What Should They Know?

Students should be able to understand how scientists do their work and how scientific knowledge is developed, critiqued, and eventually accepted by the scientific community. SI is this process. The NSES content standards for science as inquiry

for grades K-12 advocated the merit of students developing (a) the abilities necessary to do inquiry and (b) understandings about scientific inquiry (NRC 2000).

In the United States, a relatively new set of science standards define what students should be learning. Although students should be engaged in conducting scientific inquiry, the "doing" of scientific inquiry is emphasized in the new standards (NGSS 2013), within the category of "practices." The NGSS expects teachers to have students asking questions, planning and carrying out investigations, and constructing explanations. Thus in the United States, teachers are encouraged to engage their students in conducting science investigations in their classrooms. But, the explicit teaching of understandings about SI/Practices is missing from the NGSS. Although conducting inquiry, or the process skills of science, is important, students can often do inquiry without knowing how and why scientists go about their work. The efficacy of such implicit approaches to developing understandings of SI, and for that matter NOS, has been called into question by a growing body of research (e.g., Abd-El-Khalick and Lederman 2000; Akerson et al. 2000; Lederman et al. 2013; Lederman and Lederman 2004; Schwartz et al. 2002, 2004). Therefore, it is important to identify and explicitly teach the aspects of SI that can serve, in the end, to develop informed views of SI. And, of course, the major endpoint desired is the development of a scientifically literate citizenry. It is important to note that "explicit" does not mean lecture or teacher-centered instruction, as misunderstood by some researchers (Duschl and Grandy 2013). Explicit/reflective instruction engages students in reflections upon what they have done in an investigation and the implications this has for how scientists do their work and the knowledge that is produced. Such understandings are critical for the development of a scientifically literate public, considering that our citizenry is confronted with scientifically based issues upon which decisions must be made, yet few citizens engage in scientific investigations after they have graduated high school or college.

The aspects of SI that follow are empirically shown to be appropriate in the context of K-12 classrooms but can also be appropriately applied to college level students. For a more in depth elaboration of each of these aspects, see Lederman et al. (2014).

Specifically, students should develop an informed understanding of the eight aspects of scientific inquiry outlined in the table.

Statement of the Problem

Although the teaching of SI is valued around the world, there has never been a worldwide assessment of what students actually know about SI. This study sought to examine grade seven students' understandings, at the beginning of the school year, of SI in various countries/regions worldwide. This baseline study gives us data on what, if anything, students learn about inquiry in elementary school, as well as their beginning SI knowledge as they enter secondary school. It provides the global science education community a starting point from which instructional, curricula, and policy decisions can be made at the national, regional, or local levels.

Sample

The sample was taken from every continent around the world, with the exception of Antarctica. The research sites (from 18 countries/regions) were Australia ($n = 108$), Brazil ($n = 169$), Chile ($n = 142$), Egypt ($n = 109$), England (=103), Finland ($n = 149$), France ($n = 109$), Germany ($n = 96$), Israel ($n = 92$), Mainland China ($n = 378$), New Zealand ($n = 87$), Nigeria ($n = 102$), South Africa ($n = 106$), Spain ($n = 159$), Sweden ($n = 126$), Taiwan ($n = 167$), Turkey ($n = 268$), and the United States ($n = 164$). The total sample size of grade seven students was 2634 students. Alternatively, one could conceptualize the sample as actually consisting of 18 samples (i.e., one per each country/region) rather than using an overall total. If there were statistical tests used, how the sample was conceptualized could result in a unit of analysis problem. However, no statistical tests or comparisons were pursued because such comparisons would be inappropriate. The students selected for this study were based on average academic ability, representative diversity of the region, and socioeconomic background. The students were selected for this study by the contact people from each region/country, and they determined which schools represented their regions based on the aforementioned criteria. The contact researchers admittedly selected a sample of convenience. However, care was taken to select sites that reasonably "covered" each continent. There is no claim that the sample selected for each country/region can definitively represent that country/region. Such would not be humanely possible. But, the sample does give a first insight into the status of students' understandings worldwide.

There were a total of 18 primary contact people participating in this study, 1 contact person for each country/region, who almost always worked with a team of colleagues. Each site had one city with the exception of South Africa, Turkey, and the United States, which had two sites each, and Mainland China, which had three sites. In short, the contact people across the six continents were responsible for language translation/back translation to maintain VASI validity when a language other than English was used, selection of a representative sample, data collection (including paper and pencil assessments and individual interviews), completion of training in the coding/scoring of the VASI, data analysis, and the writing of location-specific aspects of the results. It is important to note that this ambitious investigation did not require the procurement of any external funds or grants.

The Translation and Back Translation Process

In order to have a valid VASI questionnaire in a language different from the original English version, the researchers in each country/region translated the English version into the local language. One researcher in each country was responsible for doing the translations. The translated version of the VASI was then translated back into English by another member of the local team who had proficiency in reading and writing

English. The back-translated version was evaluated and compared with the original VASI questionnaire by one of the authors of the instrument in order to check if the new version maintained the same meanings as the original version. In some cases, it was necessary to contact the local teams to clarify some words used in the new local version of the VASI to double check if those words maintained the same meaning or were able to capture the answers in the same way as the original questionnaire. For example, when working on the back translation between the Swedish version of the VASI and the English version, a discussion took place about the word "evidence." In Swedish this word translates into "proof" which has a different meaning in the United States. Even in countries where English was the official language, researchers had to use some alternative words according to the local context in order to have a valid VASI questionnaire. For instance, the VASI version for United States, England, and Australia had to adjust words and phrases to reflect local vernacular to better match the meaning of the original questions. For example, in the United States, we often use the phrase "flat tire." However, in England it would be called "punctured tire." Similarly, the Spanish versions for Spain and Chile are different from each other. Only after the process of translation and back translation was each team able to administer the questionnaires in each country/region. It should be clear that the process of translation and back translation is a critical issue in research and it is highly complex. The process used in this research project directly followed the well-established standards in the field (Grisay 2003; Guillemin et al. 1993; Hambleton 2002; Hambleton and Patsula 1998; Maneersriwongul and Dixon 2004; OECD 2017).

Training Sessions for Scoring the VASI

The selection and training of the contact people for this study was directed by the US researchers. This project formally began with an initial meeting at the European Science Education Research Association (ESERA) meeting. The initial timeline of the study was determined when the personnel at each research site was able to specify their local constraints. Individual meetings were arranged and conducted via Skype between each site and the primary US site. Depending on the research team, there were two to three meetings. The first meeting involved learning to administer and score the VASI. After the administration of the VASI in each country/region, each site was required to send four or five completed (but unscored) VASI questionnaires from their sample. The responses were translated into English by each local team. Then, each questionnaire was independently scored by a group of four to five researchers from the US team. Once the questionnaires were scored, a second meeting with the international local team was scheduled in order to explain how the questionnaires were scored and how the questions targeted the aspects of SI. During this meeting, each local team discussed the quality of the answers, scoring, reliability, and inter-rater agreement. In a third meeting, each team scored a new set of questionnaires for themselves and then compared their scores with the US team. This meeting allowed the local teams to "calibrate" the scoring process in order to

get 80% or greater inter-rater agreement. If additional meetings were needed, they were scheduled on a case by case basis. Once teams could reliably score the VASI with the US team, they then proceeded to establish reliability with their local team before scoring the entire set of questionnaires. They scored their entire sample and met with their local team to ensure 80% or greater inter-rater agreement for each aspect of the VASI. The inter-rater agreement established for each research site can be found in Table 1.

Data Collection

This study took place at the start of the grade seven school year which varied in timing depending on the beginning of the school year in the various continents and hemispheres. Countries in the Northern Hemisphere collected data in August/ September, and the Southern Hemisphere countries collected data in January. Each student was given a VASI questionnaire to complete in a 45–60 min time period. After administration of the VASI, the responses were scored by the primary contact person (and colleagues) in each country. Each student was given a score of no answer, naïve, mixed, or informed for each aspect of SI. Numerical scores are not used with the VASI; students' responses are categorized with respect to how accurately their responses align with the measured aspect of SI. If a respondent provided a response consistent across the entire questionnaire that is wholly congruent with the target response for a given aspect of SI, they were scored as "informed." If, by contrast, a response was either only partially explicated or thus not totally consistent with the targeted response or if a contradiction in the response is evident, a score of "mixed" was given. A response that is contradictory to accepted views of an aspect of SI, and provides no evidence of congruence with accepted views of the specific aspect of SI under examination, was scored as "naïve." At least 20% of the students were interviewed to ensure that the scoring of the VASI was accurate in representing what the students' written response meant. This insured face validity for the questionnaire. The interviews were recorded and transcribed. The inter-rater agreement reported for the VASI was 80% or better for each site.

Overall Findings

In general, this study found that grade seven students' understandings of SI are poor. However, it was apparent that, for each country or region in the study, there were some students who held more moderate understandings than others. These variations occurred depending on the curriculum, instruction, and the myriad of other factors that influence what students learn. See Tables 2, 3 and 4 for a complete set of data. The percentages in these tables may not add up to 100% due to the exclusion of missing or useable responses.

Table 1 Eight aspects of scientific inquiry

Scientific investigations all begin with a question but do not necessarily test a hypothesis	"Scientific investigations involve asking and answering a question and comparing the answer with what scientists already know about the world" (NRC 2000, p. 20). In order for scientific investigations to occur, there has to be a question asked about the natural world. Traditional experimental designs typically include a formally stated hypothesis, but this is not necessary or typical of other designs (e.g., descriptive and correlational)
There is no single set or sequence of steps followed in all investigations	Clearly, there are other ways that scientists perform investigations such as observing natural phenomena. Most often, descriptive and correlational research methodologies are employed to gather data in this field. Students need to develop not only an understanding of the variety of research methodologies employed both across and within the domains of science, but that, in general, "scientist[s] use different kinds of investigations depending on the questions they are trying to answer" (NRC 2000, p. 20)
All scientists performing the same procedures may not get the same results	Students need to understand that "scientific data does not stand by itself, but can be variously interpreted" (Osborne et al. 2003, p. 708). As such, scientists who ask similar questions and follow similar procedures may reach different conclusions, owing in part to their theoretical commitments; what scientists consider as evidence and how they handle anomalous data also influence the results of a scientific investigation. Because of this, scientists who examine the same data may justifiably come to different conclusions
Inquiry procedures can influence results	The procedure selected for a scientific investigation invariably influences its outcome. The operationalization of variables, the methods of data collection, and how variables will be measured and analyzed all influence the conclusions reached by the researcher
Research conclusions must be consistent with the data collected	Each research conclusion must be supported by evidence. Students need to understand that the strength of a scientist's claim is a function of the preponderance of evidence that supports it. The validity of the claims is further strengthened by the alignment of the research method with the research question. It follows as well then that claims must be reflected in the data collected which are analyzed to provide the evidence for said claims. Scientific knowledge is empirically based; thus, any explanations for the phenomena explored in investigations are anchored by the data that facilitates scientists' development of those explanations
Inquiry procedures are guided by the question asked	While scientists may design different procedures to answer the same question, these invariably need to be capable of answering the question proposed. Similar to the aforementioned aspect of SI, students need to understand the necessity of this alignment between research question and method; in that the former drives and ultimately determines the latter. In general, students should understand that the question determines the approach, with the approaches differing both within and between scientific disciplines and fields (Lederman et al. 2012)
Scientific data are not the same as scientific evidence	Data and evidence serve different purposes in a scientific investigation. Data are observations gathered by the scientist during the course of the investigation, and they can take various forms (e.g., numbers, descriptions, photographs, audio, physical samples, etc.). Evidence, by contrast, is a product of data analysis procedures and subsequent interpretation and is directly tied to a specific question and a related claim

Table 1 (continued)

Explanations are developed from a combination of collected data and what is already known	Investigations are guided by current knowledge. Conclusions, while derived from empirical data, are additionally informed by previous investigations and accepted scientific knowledge. Scientists need to recognize when conclusions differ from accepted scientific knowledge and determine how findings must be interpreted given what is already understood

Table 2 The worldwide average of findings for each aspect of SI

Aspect	Naïve %	Mixed %
1. Starts with a question	43.9	29.9
2. Multiple methods	54.4	33.8
3. Same procedures may not yield same results	54.0	25.5
4. Procedures influence results	40.7	33.1
5. Conclusions must be consistent with data collected	39.7	20.6
6. Procedures are guided by the question asked	44.8	20.1
7. Data and evidence are not the same	48.5	32.1
8. Conclusions are developed from data and prior knowledge	41.3	37.9

Conclusions

Overwhelmingly, the results from this study show that students around the world have an overall inadequate understanding of scientific inquiry, although there were instances in which students in a country did better than "naïve" on a particular aspect of SI. This is consistent with the few studies (i.e., because a valid and reliable instrument was not available) that have been done with secondary students and pre-service and in-service teachers (Lederman and Lederman 2004; Schwartz et al. 2008). Given the 18 independent samples from each of the countries/regions, it would be inappropriate to make blanket inferences about why these results were found. Obviously, there are numerous reasons for these results due to the obvious differences in teaching, curriculum, standards, and cultures of the various countries/ regions involved in this study. However, there are some common themes gleaned from the context-specific information received from each of the research cites. These themes are (1) lack of standards specifying understandings about SI, (2) teaching that does not make understandings about SI explicit, (3) science teaching that emphasizes only the doing of science, and (4) teaching that does not emphasize an inquiry approach. In some cases students rarely, if ever, have the opportunity to actually conduct scientific investigations. It is clear that no matter where students live worldwide, that understandings of inquiry are not cultivated. Again, it is important to note that no statistical comparisons were made among the countries as the purpose here was just to get a baseline of beginning middle school students' under-standings. Statistical comparisons across countries would be inappropriate because of the previously noted differences that exist with respect to curriculum, teaching

Table 3 Complete set of data from each country/region for each aspect of SI

Country/region	n	1. Starts with a question (%)			2. Multiple methods (%)			3. Same procedures may not yield same results (%)			4. Procedures influence results (%)		
		N	M	I	N	M	I	N	M	I	N	M	I
Australia	108	25.0	40.0	30.0	16.0	66.0	4.0	39.0	48.0	9.0	9.0	71.0	5.0
Brazil	169	83.2	11.2	0.6	74.3	10.9	0.6	82.8	9.5	0.0	81.1	6.5	0.6
Chile	142	53.5	35.2	8.5	75.4	24.6	0.0	63.4	28.2	2.8	39.4	50.7	3.5
China Beijing	166	31.3	56.0	10.8	33.1	51.8	3.0	57.8	31.3	8.4	22.3	59.0	15.7
China Shanghai	106	56.3	19.4	23.3	91.8	8.3	0.0	57.8	38.8	2.4	53.4	37.9	3.9
China Zhejiang	106	33.0	4.7	59.4	29.2	70.8	0.0	50.0	11.3	33.0	36.8	22.6	32.1
Egypt	109	30.0	55.0	14.0	50.0	47.0	1.0	51.0	23.0	23.0	47.0	30.0	18.0
England	103	39.8	35.0	20.4	56.3	26.2	10.7	58.3	19.4	11.7	22.3	46.6	5.8
Finland	149	38.3	26.8	26.2	58.2	28.4	6.5	21.5	54.4	18.1	26.8	44.3	16.1
France	109	41.0	41.0	7.0	79.0	19.0	2.0	47.0	38.0	3.0	53.0	27.0	3.0
Germany	96	41.7	28.1	26.0	20.8	64.6	13.5	62.5	20.8	15.6	39.6	31.3	25.0
Israel	92	44.2	30.4	23.2	47.8	27.5	15.9	46.4	20.7	17.8	45.7	15.6	22.5
New Zealand	87	37.9	27.6	26.4	63.2	33.3	3.4	71.3	25.3	2.3	64.4	29.9	3.4
Nigeria	102	57.8	40.2	2.0	68.6	23.5	2.0	77.5	13.7	5.9	24.5	10.8	54.9
South Africa	106	21.0	31.0	48.0	32.0	42.0	23.0	57.0	13.0	26.0	24.0	33.0	39.0
Spain	159	65.4	17.6	12.6	83.6	15.7	0.0	68.6	11.3	16.4	62.9	27.7	4.4
Sweden	126	30.2	17.5	29.4	30.2	32.5	20.6	30.2	35.7	19.8	31.0	21.4	21.4
Taiwan	167	27.5	38.9	20.4	37.1	44.3	9.0	12.0	32.3	49.7	15.0	52.1	25.1
Turkey	268	70.2	18.7	8.6	67.2	29.1	3.0	63.8	23.5	7.5	59.7	23.9	6.0
United States	164	50.6	23.2	17.7	74.4	11.6	1.2	62.8	12.2	7.3	56.7	20.1	12.8

Note: *N* naive, *M* mixed, *I* informed

approach, and cultures across the 18 countries/regions included in this investigation. As mentioned previously, the sample is really a composite of 18 separate samples, and it would be really inappropriate and unfair to compare one country's performance against other countries. It is important to note that despite all of the possible differences across countries/regions with respect to curriculum, teaching approach, and cultures, the results are quite consistent with respect to students' lack of understanding about inquiry and there seem to be some clearly common themes to explain the results.

Completion of elementary school is about half way through a student's schooling, and the data collected in this study indicate that most students hold a naïve view of most of the aspects of SI in seventh grade. These findings are not surprising as a cross-sectional study conducted in the United States found that students' under-

Table 4 Complete set of data from each country/region for each aspect of SI

Country/region	n	5. Conclusions must be consistent with data C. (%)			6. Procedure is guided by the question asked (%)			7. Data and evidence are not the same (%)			8. Conclusions are developed from data and prior knowledge (%)		
		N	M	I	N	M	I	N	M	I	N	M	I
Australia	108	24.0	21.0	52.0	23.0	20.0	51.0	15.0	74.0	3.0	16.0	58.0	8.0
Brazil	169	68.0	17.1	0.6	74.5	6.5	1.8	75.7	4.7	0.6	66.3	8.3	0.0
Chile	142	55.6	16.9	26.1	67.6	23.2	2.8	58.5	33.8	1.4	56.3	40.8	0.7
China Beijing	166	16.9	46.4	36.7	13.9	26.5	57.2	43.4	52.4	3.6	12.0	81.9	4.8
China Shanghai	106	60.7	5.8	29.6	53.4	19.4	22.3	90.3	7.8	0.0	65.5	31.6	0.0
China Zhejiang	106	29.3	23.6	41.5	30.2	7.5	60.4	30.2	64.1	0.0	0.9	45.3	50.0
Egypt	109	50.0	13.0	34.0	57.0	29.0	10.0	55.0	37.0	5.0	16.0	73.0	7.0
England	103	35.0	26.2	24.3	38.8	8.7	36.9	35.0	25.2	22.3	24.3	48.5	1.9
Finland	149	40.9	15.4	40.3	50.3	8.1	29.5	26.2	22.1	47.0	18.5	42.5	25.2
France	109	48.0	23.0	16.0	24.0	54.0	7.0	42.0	46.0	6.0	72.0	8.0	1.0
Germany	96	28.1	19.8	52.1	34.4	16.7	47.9	45.8	26.0	9.4	8.3	47.9	39.6
Israel	92	24.3	21.7	44.2	17.0	30.4	44.9	39.5	35.5	17.6	46.0	30.1	15.2
New Zealand	87	42.5	34.5	16.1	48.3	24.1	25.3	39.1	41.4	14.9	78.2	19.5	1.1
Nigeria	102	42.2	28.4	27.5	61.8	22.6	12.8	26.5	34.3	36.3	60.8	28.4	4.9
South Africa	106	33.0	17.0	48.0	53.0	15.0	30.0	51.0	20.0	18.0	14.0	67.0	17.0
Spain	159	47.8	10.7	37.7	54.1	8.8	32.1	78.0	17.0	0.6	73.6	23.3	0.0
Sweden	126	30.2	11.1	28.6	42.9	3.2	27.8	55.6	14.3	2.4	36.5	20.6	8.7
Taiwan	167	24.5	22.8	49.7	15.6	50.3	30.5	30.5	44.9	11.4	41.9	34.7	15.0
Turkey	268	54.5	17.5	26.5	72.8	10.1	9.3	60.5	29.1	6.0	48.5	32.8	13.8
United States	164	37.8	20.1	34.1	63.4	17.7	10.4	72.0	11.6	3.7	70.7	16.5	3.0

Note: *N* naive, *M* mixed, *I* informed

standings of SI do not increase between grades one to five and in the case of some aspects, their understandings decrease through elementary school (Bartels and Lederman 2017). Some may argue that the students in this investigation will have plenty of time to improve their understandings and are not that poor considering that students have just completed elementary school. However, previous studies have found that very young children (grade one and above) are able to adequately understand several aspects of scientific inquiry, science begins with a question, there is no single scientific method, and conclusions are based on data gathered and what is already known (Lederman 2012). Another study looked at grade one students' understandings of SI who came from very different cultural backgrounds; this study found that after explicit and reflective science instruction, grade one students could

understand aspects of SI regardless of their initial SI understandings (Lederman et al. 2013). Students should, at the very least, have informed views of at least some of the aforementioned aspects by grade seven. The interpretation of the results could rightfully be viewed as a conflict between having a perspective of a glass half full versus a glass half empty. Whether these results are viewed negatively or positively will ultimately be decided by how each country/region views the developmental level of their students and future studies on what students know when they exit high school, a study that we are just completing with 25 countries/regions.

Again, an important caveat, other than avoiding the temptation of comparing countries/regions, is that the primary goal of this investigation was to establish an initial baseline of what students understand about scientific inquiry. Understandings of scientific inquiry is a highly prized goal of science education throughout the world, and it is a significant component of scientific literacy (Roberts 2008). It is quite possible that not all countries/regions will care equally about each of the eight aspects of SI investigated here. Consequently, they may not be concerned that their students do not know these aspects of SI. However, this investigation provides data on some aspects that are assuredly of concern and importance to certain countries/regions, and the results can lead to changes in curricula, science teaching, and policy decisions at the local, state/provincial, and national policy decisions in science education.

Implications for Future Research

Currently, the 18 countries/regions involved in this investigation, along with an additional 7 countries/regions, are looking at graduating high school students' understandings of SI. This will provide information about how, and if, students' understandings of SI become more sophisticated as they proceed through middle and high school. It will also help decide what levels of understanding are appropriate to expect of students at the beginning of seventh grade. The final piece of students' trajectories of SI understandings can be completed by assessing elementary students' understandings of SI earlier in elementary school. The results from all three of these studies combined will elucidate a full progression of students' SI understandings from beginning elementary school to the completion of high school around the world. As mentioned earlier, some may argue that doing scientific inquiry is of ultimate importance (Duschl and Grandy 2013), and doing of inquiry will necessarily lead to understanding about inquiry. This implicit development of knowledge about inquiry is not supported by any existing research. More importantly, we argue that understandings about scientific inquiry are a necessary and critical component to the achievement of scientific literacy. The general citizenry needs to make informed decisions about scientifically based personal and societal decisions, and these decisions are based on their knowledge about how scientific knowledge is developed (i.e., scientific inquiry).

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Part III
Learning Progressions and Competences

Frantic Standstill and Lack of Future: How Can Science Education Take Care of Students' Distopic Perceptions of Time?

Giulia Tasquier , **Laura Branchetti** , and **Olivia Levrini**

Introduction

Among all the changes that the new generations have to face, one appears, in our opinion, particularly worrying: the relationship of youngsters with time. In this "society of acceleration and of uncertainty" (Rosa 2013), the younger generations are faced with an unpredictable future, a past that fails to provide clues to interpret the present and a frantic present completely oriented toward seizing the moment, sniffing out every opportunity and keeping open all possible scenarios. Sociologists have said the present is becoming "the dust of moving splinters" (Leccardi 2009), or "ashes blowing in the air", as the rapper Eminem sings in his 2017 hit *Nowhere fast*. As a result, the young are widely experiencing an alarming loss of sense and hope, as well as a new form of nihilism that leads them to live the present as though it were the only dimension that matters (Benasayag and Schmit 2006). To describe this fragmented and meaningless perception of the present, the sociologist Hartmut Rosa reports how one century ago Walter Benjamin stressed the distinction between two German words that could be used to talk about episodes of present: *Erlebnissen* and *Erfahrungen*. Erlebnissen are episodes of mere experience. When we live them, they seem never-ending and leave no trace in the memory. Because of this feature, Rosa calls them *long-short* experiences. Erfahrungen are instead experiences that leave a mark and contribute to building our identity. When we live them, they seem to pass very quickly but leave a trace in the memory. Rose calls them *short-long*

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experiences. A century ago, Benjamin complained with some concern that we were approaching an era rich in Erlebnissen and poor in Erfahrungen. Rosa stresses that today we are experiencing a world of *short-short* episodes (Rosa 2013): a frantic standstill that is at the base of what he calls "alienation from time".

These aspects challenge sociologists, policy-makers, psychologists, entrepreneurs and societal stakeholders in general, since this suffering of the young with time touches the heart and future of our societies. In particular, they interest the experts in Future Studies, a research field that investigates future as a factor influencing human perceptions and emotions and, in particular, planning and actions in the present.

We decided to give our contribution to this research field from the perspective of science education, starting from the observation that future is part of the epistemological structure of science and physics in particular can provide concepts and causal structures to push imagination toward the future.

In this paper, we focus on a module on climate change that we designed and implemented, centred on causal modelling in complex systems (Barelli et al. 2018; Tasquier et al. 2016; Tasquier and Pongiglione 2017) and enriched with activities on project planning, grounded in Goal Oriented Project Planning (GOPP) and Logical Framework Approach (LFA) (Levrini et al. under review; Venturelli 2015). As we will explain in more detail, LFA and GOPP methodology are used as tools to flesh out the inner causal structure of scientific discourse on climate change and to explore the implications on the future of mitigation and adaptation actions.

The draft version of this module was trialled in a first pilot study in 2015 (Levrini et al. 2018) where we assumed the spread of both a fragmented perception of the present and a dystopic view of future. The analysis of what happened in the pilot study, as well as testing the hypothesis, allowed us to refine our implementation and repeat the experience in order to further investigate two focal points:

> Can science teaching offer students the tools to escape the feeling of: i) a frenetic and fragmented present perceived as "dust of moving splinters"; and ii) a future perceived as a threat or as non-existent?

The paper is structured as follows: we first offer a brief overview of the literature about studies on the future; then we describe the module and the main results we achieved in the pilot study. Such a background will allow us to illustrate the second-round implementation of the same module (the original study for this paper). We will hence present this study, in terms of its context, aims, methods and results.

Futures Studies, Science and Science Education

A complex interdisciplinary field, named Futures Studies, was established after the second world war and has been investigating the issue of building the future from a wide perspective. The Future Studies community involves sociologists and philosophers, as well as STEM, economics, politics and entrepreneurship professionals. One of the main points stressed by Futures Studies experts is that *futures are not only matters of making predictions* but also ways to *open possibilities,* highlighting
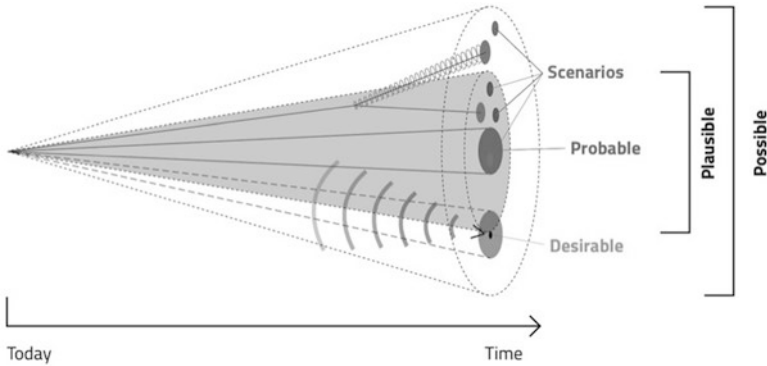
Fig. 1 The Futures cone of the Erasmus+ project I SEE "Inclusive STEM Education to Enhance the capacity to aspire and to imagine future careers" (The I SEE project (https://iseeproject.eu) is co-funded by the Erasmus+ Programme of the European Union. Grant Agreement n°2016–1-IT02-KA201-024373) (reelaboration from the Voros' cone – Voros 2003)

above all the necessity to move from one future, determined and independent on our actions and desires, to several possible futures. Within this perspective, different kinds of futures have been introduced: *possible, plausible, probable* and *preferable (or desirable)*. The relationship between them is often represented with a "futures cone" (Fig. 1), which shows a progressive widening from the probable to all the possible future scenarios.

Whilst plausible and probable futures are largely concerned with informational or cognitive knowledge, preferable futures are more emotional than cognitive since they are concerned with what people want to happen. To think in terms of preferable futures, people firstly need to agree to project themselves into the future accompanied by their current values and desires, their identities, their competences and their cultural points of view and to imagine a future scenario in which they would like to live. The ability to detach from the current situation and imagine possible preferable scenarios is the basis of the approach to futures imagination named *foresight* or *anticipation*. This approach includes back-casting activities to return to the present with the aim to design possible actions that can foster the achievement of the preferable/desirable scenario.

Fostering foresight and anticipation, as well as forecast, seems to be of extreme relevance in education, and schools, teachers and students are considered target groups for Futures Studies research. In science education new trends centred on the future can be observed; however, there are still only few studies reported. An example is the last special issue of the journal *Visions for Sustainability* (http://www.ojs.unito.it/index.php/visions) that brings together a selection of international contributions that explicitly deal with vision for the future. The issue includes approaches where STEM education stretches itself outside of its traditional bounds and acknowledges students' fraught relationship with the future and with science and technology. Another example is the interesting experience that comes from Australia, where future has been an established aspect of curriculum and pedagogy since the 1960s. In this context, Paige and Lloyd (2016) developed an educational approach based on

the assumption that integrating a futures dimension into science learning would enable students to develop a broader future-oriented perspective able to impact on many aspects of their lives; they stress merely the necessity to identify and envision alternative futures that are more socially and environmentally fair and sustainable.

We share with them the general perspective, but we try more explicitly to exploit science itself as a source of knowledge that can be turned into what we call "future-scaffolding skills", i.e. abilities to construct visions of the future that support possible ways of acting in the present with one's eye on the horizon (Levrini et al. under review; Branchetti et al. 2018).

However, the relationship between present and future is not the same in all the physical theories. To make physics productive in helping to manage irrational fear of the unknown, without removing the capacity to think about future as a realm of possibility, it is necessary to introduce concepts of complex systems, like *space of possibilities*, *future scenarios* and *projection* instead of *deterministic prediction*, *feedback* and *circular causality*.

Our notion of "future-scaffolding skills" includes the skills developed to grasp such concepts, but also transversal skills, which the labour market requires and that can support students in pushing their imagination toward the future, such as *strategic thinking* and *planning*, *risk taking, possibilities thinking, managing uncertainty, creative thinking, modelling and argumentation*.

The Module

The objective of developing future-scaffolding skills has oriented the design of a series of studies that our research group has been carrying out since 2015, aimed at designing innovative approaches and teaching modules to foster secondary school students' capacities to imagine the future and aspire to STEM careers. It is one of the key goals of the Erasmus plus project I SEE "Inclusive STEM Education to Enhance the capacity to aspire and to imagine future careers", which started in September 2016 (www.iseeproject.eu).

In order to concretely address our overarching goals, the first module we designed concerns climate change because of two main elements pertaining to this topic: (i) connections to fundamental and important scientific contents and scientific practices (patterns of reasoning, arguing, explaining) and (ii) *future relevance*, in the sense that it represents a significant societal challenge widely debated also for its implications on the future. Other topics on which we built similar modules within the I SEE project are quantum computing and artificial intelligence (Branchetti et al. 2018).

The module design was carried out according to the following principles:

– Making the scientific temporal patterns and causal models explicit, by introducing and discussing basic concepts of complex systems (Levrini et al. 2018; Tasquier et al. 2016); from an operational point of view, this implies the design of teaching activities aimed at developing special skills: skills helpful for distinguishing between linear and circular causality, within scientific texts, recogniz-

ing the nature of the causal links and individuating possible feedback loops that can be found starting from a text.

– Integrating the societal and vocational dimensions (Stuckey et al. 2013) with the conceptual and epistemological ones in science teaching; this implies, operationally, the design of teaching activities aimed at developing special transversal skills: skills helpful for mapping the complexity of the present into a comprehensive picture and engaging with the future significance of the issue.

– Making the learning of science relevant from a personal perspective (Kapon et al. 2018; Levrini et al. 2015, 2018; Stuckey et al. 2013); this operationally implies the enrichment of science teaching with activities aimed at developing personal engagement, creativity as well as foresight and anticipatory attitude and encouraging students to take the agency for their future.

In accordance with the set of principles, the module was set out into three parts (Fig. 2) and its design and/or implementation involved professional scientists in climate change (RR, SD, AB), experts in European project planning (MR, AM), experts in physics and mathematics education (OL, GT, LB), Master's students in physics education (IV, EB) and a secondary school teacher (PF).

In the first part of the module, students are introduced to the topic of climate change through a general introduction to climate models and issues at the centre of scientific controversies, such as the anthropogenic causes of climate. Students are shown the abnormal temperature trend over the last 150 years and some consequences of this – such as melting glaciers, rising sea levels, and increased frequency of extreme phenomena (river flooding, drought, heat waves and so on) – and guided to recognize positive and negative feedback loops. During the following lab session, a simplified situation is reproduced in order to build a greenhouse model able to explain how and why a change in the make-up of the atmosphere could produce a change in the average of the Earth system temperature; the model is discussed in terms of energy balancing. This experiment serves to introduce a phenomenological relation between absorbance and temperature and discuss it in terms of temporal and causal structures, paying particular attention to the concept of feedback and circular causality. After that a special activity is implemented in order to help the
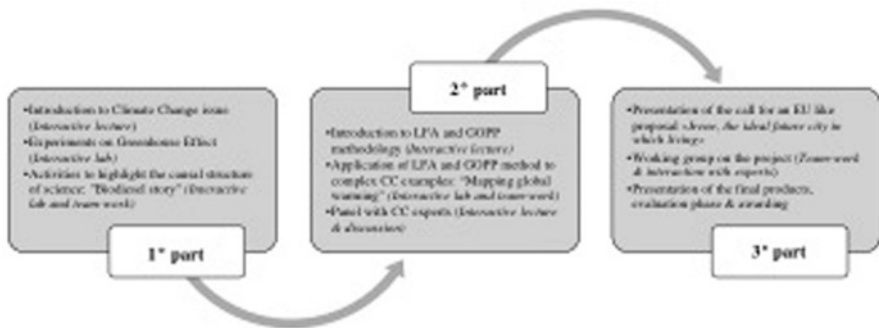

Fig. 2 The three-pronged structure of the module

students distinguish between linear and circular causality, within the scientific texts, recognizing the nature of the causal links and individuating possible feedback loops that can be found starting from the text. The activity consists of reading the "Biodiesel Story", a text on the focal problem of use and production of biofuel, and some tasks that guide toward the construction of a cause-effect map. Students are required to read the text, identify the problems within the text, organize and hierarchize them, find the cause-effect links among them, draw the map by making explicit the reasoning beyond the arrows that connect the problems and search for crucial points in which it is possible to identify or create feedback loops.

The second part of the module focuses on activity aimed at developing skills for analysing the present situation. In this session, the students are introduced to GOPP and LFA, a project planning method widely used within the European Commission (https://ec.europa.eu/europeaid/sites/devco/files/methodology-aid-delivery-methods-project-cycle-management-200403_en_2.pdf). This method foresees, as the first stage of project design, an analysis of documents intended to build the "state of art": the construction of *problem* and the *objective trees*. We prepared different texts of increasing complexity, with the last being a synthesis of the IPCC report on climate change. The entire document is rather long since we wished to include the many dimensions of climate change (scientific, technological, political, social, urbanistic, educational and so on) and encourage each student to find the type of problems that could resonate with their own intellectual, political or emotive views. The students are asked to analyse the document and build a map, by pointing out the problems and their causal relations (the problem tree). After construction of the problem tree, the module sets out that the students be guided in turning it into an objectives tree. In Figs. 3 and 4, we report a simple excerpt of the document and its analysis in terms of a problem tree and, hence, its transformation into an objective tree.

In the third part, the students are asked to work in groups of four or five and choose a specific focus (e.g. transportation, tourism, city planning, technological innovation) and to write a project as response to a call entitled "Rimini [their city], the ideal future city in which to live". The design of the project is guided by a typical template of European proposals, consisting of general and specific objectives, team description, stakeholders, expected results, Gantt chart and impact. In order to encourage the students to take *agency* of their future, develop *foresight/anticipation and back-casting* attitude, enhance *creativity* and feel *personally engaged* (our third set of design principles), the activity requires them to choose a part/dimension of the goal map wherein they wish to act (*agency*), think about a desirable scenario and an ambitious goal they hope to reach (*foresight/anticipation*), look for a creative idea that could characterize the project (*creativity*), build a working team by imagining possible professional roles for themselves in the project (entrepreneurs, lifeguards, architects, policy-makers, researchers, teachers and so on) (*personal engagement and identity formation as future professionals*) and articulate the project idea into a structure of specific objectives, strategies and time graph *(agency through back-casting).* To accomplish these activities, the students are requested to present their projects, which are evaluated by a committee of experts.
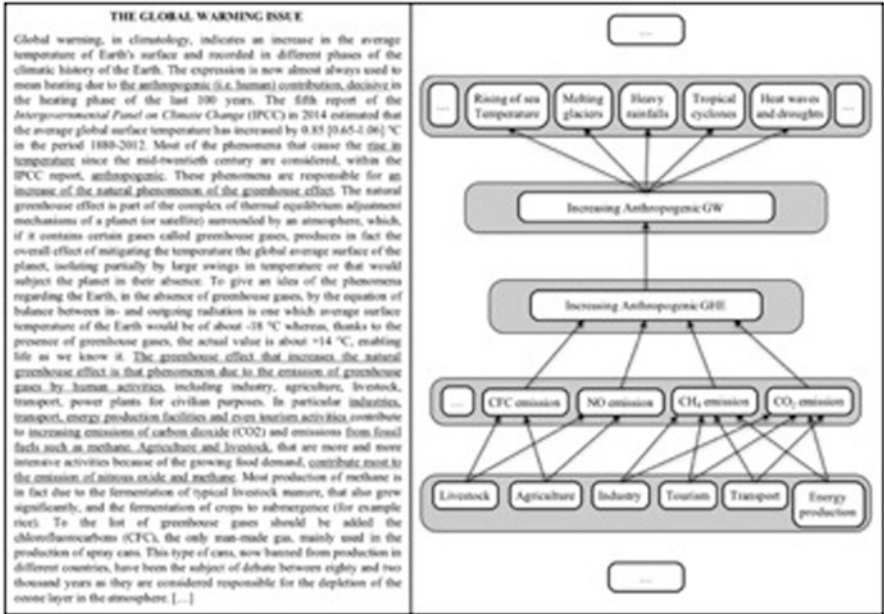
Fig. 3 Example of problem analysis activity: excerpt of a text to be analysed (*on the left*) and example of a problem tree (*on the right*)
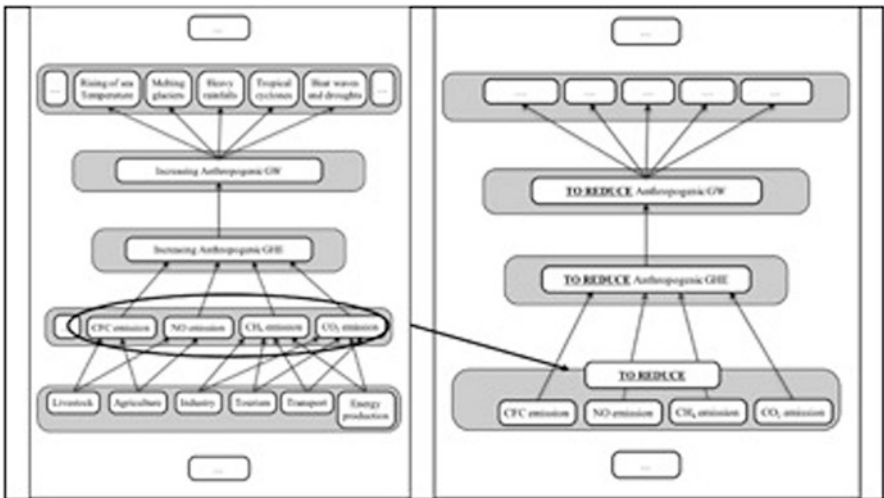

Fig. 4 Example of problem analysis activity: transformation of the problem tree (*on the left*) into an objective tree (*on the right*)

Background: Context and Results of the Pilot Study

The module was tested for the first time in a grade 12 class of the Scientific Lyceum A. Einstein in Rimini (Italy). The implementation consisted of 7 extracurricular sessions (3–4 h each), and the activities were designed for volunteer students of the class: 24 (15 females and 9 males) out of 25 students participated in the project. Such an implementation represents the pilot study of this research.

The main findings reveal a significant impact of the activities on students' perception of the present and the future (Venturelli 2015): the present from problematic became comprehensible and cognitively manageable and the future from far and unimaginable became conceivable as a set of possibilities.

Furthermore, the analysis of individual interviews showed that the activities *enlarged* students' horizons and, in such a wider picture, the future was perceived as *closer* and within their reach. Operationally, in the pilot study, we identified markers to help recognize nuances in students' descriptions of their sense of "widening the perspectives", and we discovered that widening (Wid) could refer to:

– The knowledge of the topic (of climate change and related aspects like migration, increase of vulnerability) (Wid1).
– New ways of thinking and looking at the problem (Wid2).
– The awareness and confidence in their own potential and their role of agents (Wid3).
– The range of possible actions (Wid4).

Thanks to this process of widening, the future was described as "closer" and more approachable (Ap), in several senses:

– Closer in time, in the sense that the year 2030, from far and unimaginable, became thinkable as a set of possibilities (Ap1).
– Closer to reality, in the sense that it became approachable through concrete actions in the present (Ap2).
– Closer to themselves, in the sense that the future became within their reach and they found ways to see themselves as agents of their own future (Ap3).

In light of these results, we planned a second round of implementation where we refined the tools for data collection in order to evaluate the robustness of the previous results and gather information about the activities that played a specific role in triggering processes of change.

The Study: Context, Aims, Data Sources and Methods of Data Analysis

The second implementation of the module, which we discuss in this paper, was carried out at the Department of Physics and Astronomy of Bologna in June 2017. It involved a group of 39 students 17–18 years old (16 females and 23 males) from different high
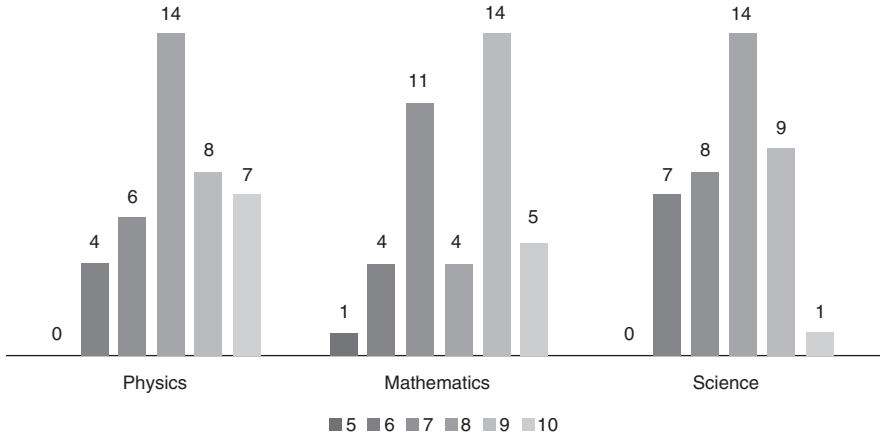
Fig. 5 Students' level of performance in physics, mathematics and science at school. (On the x-axis, the distribution of students' marks is shown for each subject matter. Marks up to 5 indicate an insufficient level, 6 and 7 an adequate level, 8 and 9 a good level and 10 represents excellence)

schools. The context of implementation was a summer school within an Italian national project called PLS, which aims to guide students in their choice of university studies. The students came from different types of schools, Scientific Lyceum (28), Classical Lyceum (4) and Vocational School (7), as well as from different parts of the region: Bologna (12), Hamlets of Bologna (12), inland towns (5) and seaside towns (10). The group included students with different level of school performance in the scientific subject matters (physics, math, science), as it is shown in Fig. 5.

The summer school represented an extra-school activity in which students were selected on voluntary basis. The summer school lasted 5 days (6–8 h per day). Before, during and after the implementation, we collected the following data: written essays, questionnaires, audio and video recording of the activities, researchers' notes and students' projects.

The study is methodologically framed within the design-based research (Cobb et al. 2003; Plomp and Nieveen 2013) and is part of an iterative process of designing, testing and revising the modules, according to back-and-forth dynamics between theoretical hypotheses and empirical results. Consistently with the design-based research methodology, the study has an explicit theoretical orientation (Cobb et al. 2003; diSessa and Cobb 2004) that enriches the goal to design and realize good practices with the purpose of explaining why a classroom practice is more or less successful. Within this framework, two specific research questions oriented the data collection and analysis, one empirical and one theoretical:

RQ1   What kind of effects did the module have on students' perception of time (both present and future)? Are such effects comparable/compatible with the empirical preliminary results we achieved in the pilot study?

RQ2   What contribution does the study offer to the definition of future-scaffolding skills?

Table 1 Questions from the post-questionnaire

Qa	*Did the summer school give you the tools to face the present? If so, please explain in a few words in what way this is true*
Qb	*Did the summer school give you the tools to face the future? If so, please explain in a few words in what way this is true*

In order to answer the RQ1, we used the same pretest/post-test approach as in the pilot study. In particular we applied the same tool to collect data about students' perceptions of the future before teaching and a comparable final questionnaire. The pretest was a written essay where students were required to "Imagine yourself on a spring day in 2030 and imagine how the phenomenon of global warming may have changed the environment around you and the place where you think you will live". In the final questionnaire, we included two questions, general enough to leave the students free to answer as they wished, but also focused enough on the perceptions of present and future to check the results of the pilot study and to confirm/discuss them (Table 1).

The other data we collected (audio and video recordings of all the meetings and group work; the projects designed by the students; notes of researchers) have been used to triangulate the analysis of the pretest/post-tests and to monitor the overall process.

To answer RQ1, the data have been analysed through a semi-qualitative methodology of data analysis (Anfara et al. 2002) targeted at building a synthetic picture of what happened in this context that was comparable with the pilot study (Levrini et al. under review; Venturelli 2015). To guarantee the reliability of results, every stage of data analysis was triangulated among researchers; as in the pilot study, to evaluate the results' relevance in a broader sense, the data and the results have been tested against results from the research literature. Particularly, we compared our results with the Eurobarometer (2015), which presented a qualitative survey illustrating the general perceptions of scientific and technological innovations and spontaneous projections regarding tomorrow's society, as well as possible scenarios shaping the future. As we will show during the analysis, we used the perceptions and scenarios that emerged from the qualitative survey of Eurobarometer to triangulate what emerged from our analysis.

In order to answer the second research question (RQ2), we looked at the data through a qualitative lens designed to recognize eventual patterns of "scaffolding signals". We applied the researchers' triangulation, practice reflexivity as well as member-checking (with all the participants of the study, i.e. teachers, students, and researchers) (Anfara et al. 2002), to highlight not only what happens in a specific teaching/learning experience but also to search for an interpretation of why, when and how it happened (Cobb et al. 2003).

Results

Students' Initial View

Since the goal was to make the results comparable with the pilot study, we analysed the initial essays with the same criteria used in the pilot and built the same graphs (Levrini et al. 2018). In order to check whether students' reactions on the future were comparable with the reactions we encountered in the pilot study, we analysed the written essays in two ways: first we carried out top-down analysis by applying both the categories we obtained from the analysis of the pilot study and the Eurobarometer results; then, we carried out a bottom-up analysis by posing the same leading questions we used for the pilot study to check out the coding and, if necessary, to revise it.

The first thing we analysed was how many students perceived changes in the future: 87% of students described their future by highlighting changes with respect to the present. Out of the remaining 13%, 3% drew pictures similar to the present, and the others were not able to imagine or describe a future scenario. This distribution shows, like in the Eurobarometer (2015), the presence of students who are not able to imagine the world differently. In our pilot study, this fraction was almost one third.

In Fig. 6 we report the dimensions of change that the students who perceived a future different from the present used to describe their scenario in the essays. A bottom-up process of analysis led us to recognize the same dimensions that the students used for describing 2030 scenarios in the pilot phase: environmental (25), technological (30) and social (7) with a specificity about health (4) and political (2).

As for the environmental dimension, students highlighted changes in the surrounding environment mostly at a level of climatic consequences. Generally, a vision of revolutionary change is not prevailing, but there is intensification of aspects already traceable, like rising sea levels or floods or waves of drought and desertification (for the negative views), or like the mitigation of climate problems, thanks to a decisive emissions reduction and the extension of parks and green areas (for the positive views).
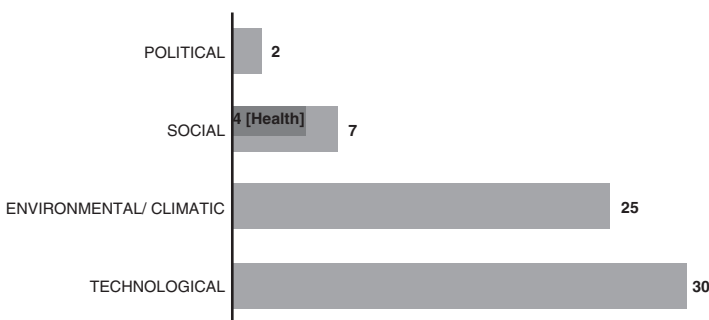

Fig. 6 Dimensions of change in the descriptions of students' 2030 scenarios

The political dimension is very infrequent in the essays. The two students who talked about it stressed: the importance of political and economic choices to govern climate changes and make this world more eco-friendly; worry about future demagogic policies, and the fear that people are not able to develop a critical consciousness.

The social dimension appears more frequently than the political aspect, but generally it is centred on the problem of how social media and new technologies can change human relationships. Within this dimension the problem of health was mentioned by four students. It was absent in our pilot study, whilst it is a relevant point in the Eurobarometer survey.

As in the pilot study, the technological dimension was definitely the most diversified and frequently mentioned by the students. Students' descriptions of 2030 range from science-fiction perspectives (5) to low-tech worlds (10), passing through scenarios where already-existing technologies are more widespread (14) or new technological innovations are produced (5) (Fig. 7).

This distribution highlights a well-known and substantial fact, stressed by the Eurobarometer and already pointed out in our pilot study: the ambivalent relationship of the young with technology, torn between desire for a life that increasingly benefits from technological developments and a sense of nostalgia toward an idealized low-tech past, especially as regards human relationships.

Another very well-known trend that is also confirmed by these data is the negative and pessimistic attitude toward the future, as well as the tendency to deny or delegate the problem to other people (scientists, innovators, policy-makers). Figure 8 shows students' attitudes toward the future where it emerged that, as in the pilot study, very few of them (5) described the future as a stimulating challenge that could allow humans to explore new social and political structures and to develop new technologies ("All these problems, however, will be opportunities to develop new technologies. If these problems can be exploited, scientists can make new discoveries and achieve great results"), whilst many (25) express fear and anxiety ("I fear that these policies that focus purely on economic profit and carelessness of environmental health could lead to terrible consequences"), and a significant number (11) delegates or trusts that someone else or human adaptability can address the
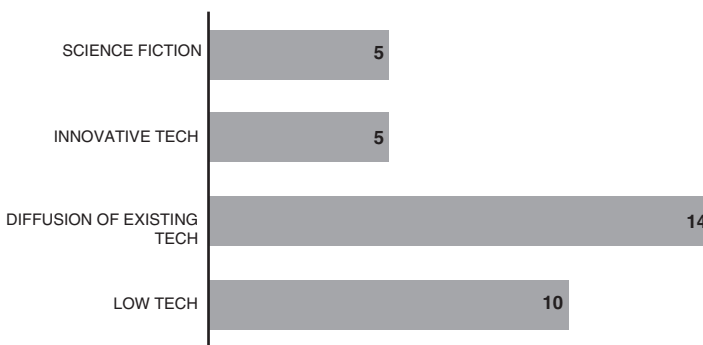

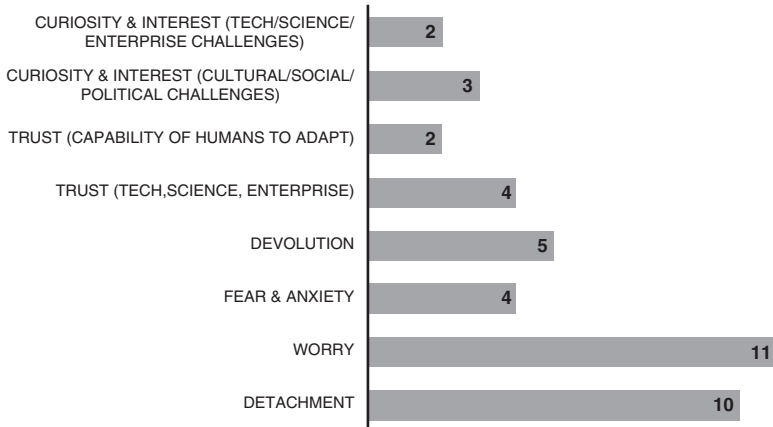**Fig. 7** Relation with technologies

Fig. 8 Students' attitudes toward the future

problems ("My family and I are aware that we cannot do much to improve this dramatic situation, as the big change should have already been implemented at the political level.").

To sum up, the analysis shows that the sample of this study has an initial view of the future that is comparable with the preliminary picture held by students involved in the pilot study (Levrini et al. 2018). This picture confirms the widespread negative and pessimistic feeling toward the future as well as the tendency to deny the problem and/or remove the future from their personal horizon. From a methodological point of view, this analysis allows us to state that the two samples were comparable for the initial picture of the future.

Students' Final Views

The final picture of students' views was constructed by analysing students' answers to the open-ended questions of the post-questionnaires reported in Table 1.

As we anticipated, in the pilot study, we surmised that some activities of the module contributed to enabling the students to address the perception of a fragmented present and to build a global comprehensible view. It seemed reasonable to guess that the activities on the maps played a crucial role in such a change, but we did not have data to support this claim. Hence, through the analysis of the answers to Qa, we checked *whether* students report *similar changes* in the perception of the present and, if so, *which activities* fostered the change.

From students' answers to Qa, an awareness emerged very often about the relevance of thinking about the present and that something happened in their perception: "the summer school taught me to be more effective and efficient in analysing problems […] I understood that the analysis of the present is very important, above all as a basis for changing the future (S26)".
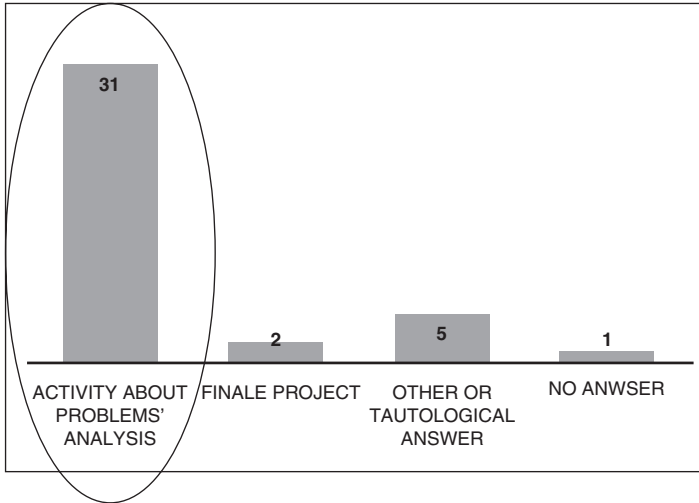
Fig. 9 Activities mentioned by the students

In their answers, 31 out of 39 students mentioned the activities on text analysis and map building as key sources of tools to deal with the present (see Fig. 9). We aggregate these markers, and we identified them as skills that help the students to face the present (noted as PS).

Students' answers were rich enough to allow us also to figure out what skills they believed to have acquired to face the present (Table 2). Some students stressed the feeling that they learnt to recognize and select important details and facts from a previously confused ocean of information (PS1). Others highlighted that they learnt to break down a big problem into smaller problems (PS2) and to organize and hierarchize them (PS3). Many students found relevant the way they learnt to organize the problems within a network of cause and consequences (PS4); other students stressed the importance of carrying out an accurate and deep analysis before making any decision and identifying solutions (PS5). Finally, others focused on the importance of distinguishing between problems, objectives and solutions (PS6). Table 2 shows the different aspects mentioned by the students with some descriptive categorizations for each of the aspects, whilst in Fig. 10 the distribution of the students (x-axis) over the different aspects (y-axis) is reported.

Several students stress more than one aspect, as the following examples show:

The summer school taught me to analyse the problem by breaking it down into problems (**PS2**) and finding a cause-effect relationship (**PS4**) in order to organize these problems in a hierarchical way (**PS3**). (S20).

At the beginning I had a lot of difficulty in finding solutions to problems that were difficult to identify (**PS1**). By comparing ideas with others and spending a lot of time on a problem to try to analyse it and break it down (**PS2**), in the end I managed to identify many problems and solutions (**PS6**). (S2).

Table 2 Skills that the students perceive they have learnt to face the present (PS)

(PS1) Selection or focus on pieces of information	The summer school taught me how to get a lot of different information from a text. Now I can pay more attention to the details that, before this experience, I took for granted or thought were not important. (S3)
(PS2) Breaking down a big problem into smaller problems	The summer school taught me to analyse the problem by breaking it down into problems [...]. (S20)
(PS3) Organize and/or hierarchize problems and information	Through the summer school I learned to analyse problems better, organizing them clearly in maps and hierarchizing them. […] (S22)
(PS4) See a problem in a network of causes and consequences connected to it	The summer school has provided me with a new way of seeing the same situation from different points of view in order to understand it better, to understand the various causes that compose it and the consequences it could have. (S7)
(PS5) Anticipate the analysis with respect to the solution	The summer school taught me how to start from the problems and analyse them in depth before arriving at the formulation of possible solutions. (S8)
(PS6) Distinguish between problems, objectives and solutions	Thanks to the summer school I developed a discrete process of analysing the problems of the present, in particular, analysing the initial problem and its "subproblems", then identify the general and specific objectives and finally identify possible solutions for the objectives. (S27)
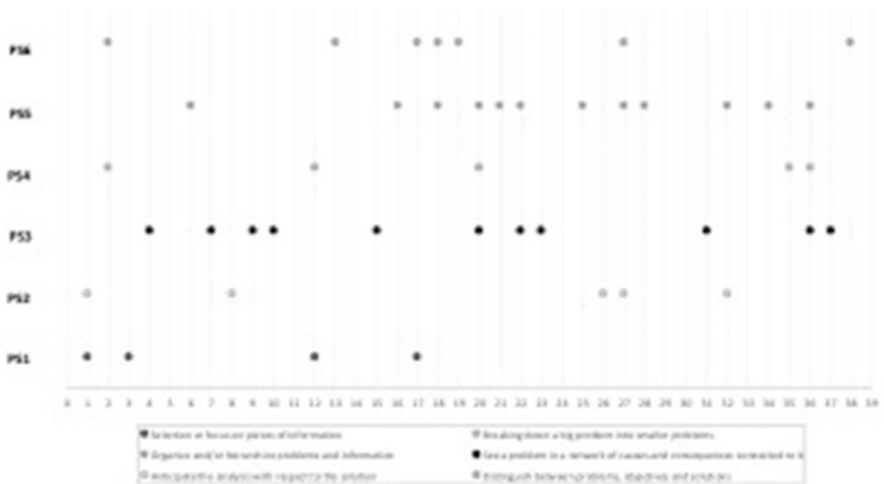
Fig. 10 Students' distribution along skills they have learnt to face the present (*x-axis,* the 39 students who participated in the summer school; *y-axis,* skills described in Table 2)

The first finding of our analysis is that these data confirm what we discovered in the pilot study, i.e. the activities revealed the potential to impact students' perception of the present. More than in the pilot study, it emerged that the activities encouraged

students to *consciously* develop special skills. We find it very interesting that all the skills they describe are *structural*, i.e. skills that serve to organize the impelling, fragmented and chaotic reality of present from selecting pieces of information among the indistinguishability of the background (PS1); to organize pieces of information into relations that can be hierarchical (PS2), causal (PS3) and temporal (PS4); and to distinguish logical codified structure of reasoning among them (PS6).

In order to check whether students' reactions on the future were comparable with the reactions we encountered in the pilot study, we analysed the answers to Qb (*Did the summer school give you the tools to face the future? If so, please explain in a few words in what way this is true*) in two ways: first we carried out top-down analysis by applying the markers we bootstrapped from the data of the first study and then we carried out a bottom-up analysis to check the validity of the markers for this study and if with these markers we reached a level of saturation. Figure 11 reports the results of the analysis. The graphic shows the high frequency of these markers in students' comments and the introduction of a new marker. In Table 3 we illustrate the markers by giving a refined definition as a result of the combined process of analysis, by reporting examples of how students directly describe the impact of the activities on their perception of future.

Both the frequency and the words used by the students confirm what we already observed in the pilot study but also add a new nuance in the markers of widening (Wid5) that we did not observe in the pilot study. We interpreted the emergence of this new pattern as the result of the introduction of the panel with experts within the module (see Fig. 2). Indeed, the panel was very appreciated by the students since it opened their imagination on research and technological areas and allowed them to see possible STEM-related professions that they did not know.

Concerning the issue of the impact of the activities on students' future-scaffolding skills development, some students highlighted that the activities on project design fostered the development of other skills, which we can call *dynamical* skills and that we identified transversally in the students' answers. We grouped them into five preliminary categories, to be clarified in future experiments. They appear *dynamical* since they refer to *back-and-forth processes* of (i) thinking big and thinking small,
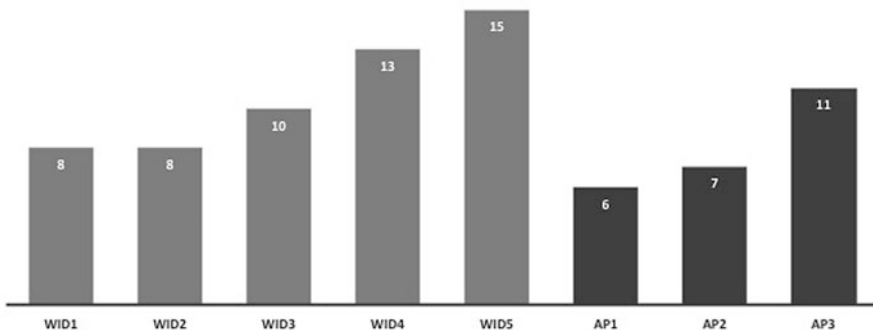

Fig. 11 Frequency of the markers in students' words

Table 3 Description of the markers by using examples of students' expressions

(Wid1) widening in their knowledge of the topic (of climate change and related aspects like migration, increase of vulnerability)	The explanation of the CC problem has heightened my awareness of the threat it poses to humanity and the whole world. My awareness of the loss of biodiversity and the increase of extreme phenomena has increased, thus pushing me to think more about this problem and to discuss it at home, with friends and in various contexts to find solutions together (S22)
(Wid2) widening in the range of new ways of thinking, approaching and looking at the problem	The summer school has led me to think more widely about the future, that is, to take into consideration many different aspects; at the same time, it made me take a more narrow and focused view, that is, only to think of a small situation and analyse that, projected into the future. (S12)
	He made me understand that to discover new things, you have to take your feet off the ground and try not to limit your imagination. (S7)
(Wid3) widening in the awareness and confidence in the role of citizens and individuals	One goal that I think I have achieved this week is the ability to observe and understand the present and then be able to project into the future. This is also the basic message for acting as eco-sustainable citizens: There is no future without a present. The course further developed my awareness as a citizen, also pushing me to the dissemination of these themes. (S21)
	Surely thanks to this summer school I have understood how I can contribute to improve the environment around us and in the future, I will do my best to work in this area and improve living conditions. (S2)
(Wid4) widening in the range of possible actions, strategies and concrete solutions that can be undertaken	In the initial essay I had thought about how the world could become and not how I wanted it. After this summer school, I realized that if we continue to treat our world like that, it will only get worse, but at the same time I am more serene because I have seen that there are many things that are being done and that I did not imagine existed. (S12)
	The summer school has certainly made me discover new possibilities, new perspectives and new ways of intervening. (S23)
(Wid5) widening in the awareness and confidence toward research, technologies and experts in the field	Honestly, I feel more confident now that I have met several people working to fight the CC and now that I have seen some strategies in place to combat the phenomenon. (S18)
	Initially I was afraid there were no technologies and research ideas to change and influence the future, now I understand instead that they are present. (S26)
(Ap1) closer in time, in the sense that the year 2030, from far and unimaginable, became thinkable as a set of possibilities	The school certainly made me discover new possibilities, new perspectives and new ways of intervening. The world I had described in the initial essay was quite utopian and therefore I did not consider it feasible. But now I think we could approach this future and it can be achievable (S23)

(continued)

Table 3 (continued)

(Ap2) closer to reality, in the sense that it became approachable through concrete actions in the present	I understood that the means to change the future are already present, we need to analyse a way to apply them and then change the future. I also understood that the change that must take place in the future to allow human survival is now extremely concrete. I believe the future is scientifically and technically more feasible and approachable (S26)
(Ap3) closer to themselves, in the sense that the future became within their reach and they found ways to see themselves as agents of their own future	Now I can imagine a more positive future than before. I consider it even more achievable because in these weeks I have gained more hope in the future. The creation of the project helped me to understand that thanks to our actions in the present the future can be better and, in this way, I have eradicated my fears (S24)

(ii) thinking in the present and thinking in the future, (iii) acting as an individual and as a society, (iv) imagining new possibilities and planning concrete actions and (v) desiring and keeping feet on the ground. We do not have enough data to check this hypothesis, but we believe it feasible that the activities enabling students to expand their horizons and perspectives (Wid1–Wid5) and sense the future as more approachable (Ap1–Ap3) and also have the potential to develop those specific dynamical skills. Vice versa, in the next implementation, we will make an effort to refine the activities to engage students more explicitly in these dynamics. Indeed, we consider the discovery of this type of skill a new result, particularly important for responding to our second research question: the study contributes to the definition and recognition of *future-scaffolding skills* by offering two new sets of skills that enable students "to construct visions of the future that support possible ways of acting in the present with one's eye on the horizon" (Levrini et al. 2018); these sets include *structural skills* needed to build comprehensive pictures of the present and *dynamical skills* needed to perceive the future actively and use it to widen the imagination and, contextually, make decisions in the present.

Conclusions

In this paper we reported the analysis of the second implementation of a module on climate change that we had designed to exploit science education as a context for the development of what we called future-scaffolding skills (Levrini et al. under review).

Data collection and analysis were carried out to answer two research questions, one more empirical and one more theoretical. The first question concerns the comparison of this study with the pilot study in order to check whether we can confirm and reinforce the empirical results achieved previously. The second question concerns the contribution that this study could offer in developing our definition of future-scaffolding skills.

The results confirm that most of the students' reactions observed in the pilot are recurrent and were observed also in the second study, so they seem not to be idio-

syncratic of the first sample of students, but a consequence of the activities. Furthermore, they allow us to focus more and more effectively on the types of skills that the activities are potentially able to foster and that can be included in the future-scaffolding skills. In particular, we pointed out *structural skills* that have the potential to enable students to move from an image of present as "ashes blowing in the air" (Eminem) to a reality where important details and information are recognizable over an ocean of information (PS1); big problems are broken down into smaller problems (PS2), organized and hierarchized (PS3); problems are situated within a network of cause and consequences (PS4); an accurate and deep analysis is temporally precedent to any decision and solutions (PS5); and problems appear logically separated from objectives and solutions (PS6).

Then, we pointed out *dynamical skills* that seem potentially effective in overcoming the perception of frantic standstill and of going "Nowhere fast" (Eminem). They are abilities to move back and forth between (i) thinking big and thinking small, (ii) thinking in the present and thinking in the future, (iii) acting as an individual and as a society, (iv) imagining and planning concrete actions and (v) desiring and keeping feet on the ground.

The discovery of these skills provides an important contribution to our theoretical reflection about the definition, recognition and evaluation of future-scaffolding skills. Indeed, our notion of future-scaffolding skills, which initially has offered a list of scientific and transversal skills (Branchetti et al. 2018; Levrini et al. under review; Tasquier et al. 2018), was enriched by features (structural and dynamical) that can provide students' thinking with a scaffolding to push imagination forward and look back in the present with a horizon of sense.

Going beyond the detailed analysis of the impact of the module on students' skills development, the finding that we consider most relevant is the sense of hope and calm that the students expressed at the end of the module in both the studies. We sincerely hope the module implementation has been experienced as a short-long moment (*Erfahrungen*) for them. In any case, the results suggest that science education can play an important role to support the young in addressing this dramatic moment in which social media, politics and society assail them with the sense of lack of future.

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What Does It Mean to Understand a Physics Equation? A Study of Undergraduate Answers in Three Countries

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Introduction

As a discipline, physics is concerned with describing the world by constructing models, the end product of this modelling process often being an equation. As such, physics equations represent much more than a finalized, ready-to-use calculation package – to physicists they are the culmination of a whole range of actions, assumptions, approximations and historical discoveries. Moreover, physics equations are not simply stand-alone entities, rather they are intimately bound up with other equations. Together, this web of equations represents an integrated, coherent whole that signals the way the community of physicists view the world.

Clearly, such a nuanced, expert-like understanding of physics equations is not spontaneously available to undergraduate physics students when they meet an equation for the first time. In this respect, research suggests that we should not expect students to display conceptually coherent understanding across settings. Rather it has been suggested that understanding is built up from context-dependent *knowledge in pieces* (diSessa 1993, 2018). In this characterization, different aspects, or ways of viewing the same phenomenon, are leveraged in different settings. Students gradually develop their understanding in two ways: by forging links between these

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separate 'pieces of knowledge' and by coming to appreciate the usefulness of a given 'piece of knowledge' for a given task. Educationally then, we are interested in identifying these pieces of knowledge – in our case the *range* of ways that students understand equations. What are students' default positions with respect to equations? Which aspects of equations do students tend to focus on and which aspects tend to go unnoticed? Once we have documented the range of ways of understanding, the next task concerns how to help students discern other aspects of equations than those they may initially notice. Do the tasks that students are presented with in their undergraduate education encourage them to move towards a more nuanced, coherent, holistic understanding of physics equations?

Research Background

To date, the literature on physics equations has focused on two areas: *use of equations in problem-solving* and *student attitudes and beliefs about physics equations*.

Equations in Problem-Solving

Research carried out on undergraduates' use of physics equations for problem-solving suggests that many students in calculus-based courses focus their attention exclusively on selecting an equation and substituting in known values – the so-called plug and chug approach (see Tuminaro 2004). This behaviour has been candidly characterized by Redish:

> Most of our students don't know what you and I mean by "doing" science or what we expect them to do. Unfortunately, the most common mental model for learning science in my classes seems to be:
>
> • *Write down every equation or law the teacher puts on the board that is also in the book. Memorize these, together with the list of formulas at the end of each chapter.*
> • *Do enough homework and end-of-the-chapter problems to recognize which formula is to be applied to which problem.*
> • *Pass the exam by selecting the correct formulas for the problems on the exam.*
> • *Erase all information from your brain after the exam to make room for the next set of material.*
>
> I call the bulleted list above 'the dead leaves model'. It's as if physics were a collection of equations on fallen leaves. […] These are each considered as of equivalent weight, importance, and structure. The only thing one needs to do when solving a problem is to flip through one's collection of leaves until one finds the appropriate equation. I would much prefer to have my students see physics as a living tree! (Redish 1994: 799)

One significant milestone study on student understanding of equations is that of Sherin (2001) who examined students' ability to construct and analyse physics equations. Sherin found that students used what he called *symbolic forms* in their

attempts to understand equations. In essence, symbolic forms relate to mathematical relationships between variables where the forms themselves can be seen as templates that students can use to make sense of equations. For example, in the equation $\lambda = h/p$, if students focus on what Sherin terms the "*prop–*" symbolic form then they focus on the fact that p is the denominator and thus notice that lower values of p lead to higher values of λ. Further research on the use of physics equations for problem-solving can be found in a useful overview by Hsu et al. (2004). For more recent examples on the same theme, see Hegde and Meera (2012) and Eichenlaub and Redish (2018).

Attitudes and Beliefs About Equations

Research has also shown that the attitudes and beliefs that students hold about physics equations can have an impact on their learning and the techniques they use to problem-solve. May and Etkina (2002) studied student ideas about what they learned and how they learned it using written self-reflections and concluded that student gains on standard conceptual measures were related to their ideas about knowledge itself. Students who had low gains tended to focus on the importance of having an equation written down and using it to get to an answer. This is in contrast to high gain students who mentioned using equations to investigate cause-effect relationships, make analogies and perform derivations. High gain students were also less likely to mention specific equations as something they learned, instead mentioning concepts, skills and the interpretation of results.

Lising and Elby (2005) used videotapes of interviews with one student and her group work to argue that the student kept formal (mathematical) reasoning separate from informal (everyday, intuitive) reasoning. The barrier that the student's beliefs placed between formal and informal reasoning made it difficult for her to identify and resolve errors when reasoning with equations.

Very little research has examined what students themselves think it means to understand a physics equation. Domert et al. (2007) interviewed 20 students from different levels at three Swedish universities, asking the question: *When you say or feel that you understand an equation, what does that mean?* The data resulted in the identification of seven components of the understanding of physics equations: *being able to recognize the symbols in the equation in terms of the corresponding physics quantities*; *being able to recognize the underlying physics of the equation*; *recognizing the structure of the equation*; *establishing a link between the equation and everyday life*; *knowing how to use the equation to solve physics problems*; and *being able to know when to use the equation*. Comparing the results of this work to the previously mentioned research, *knowing how to use the equation to solve physics problems* was frequently mentioned by low-gain students in the May and Etkina (2002) study, whereas failure to *establish a link between the equation and everyday life* was identified as the main barrier to learning in Lising and Elby (2005) study.

Finally, drawing on the work of Domert et al. (2007), Hechter (2010) asked a small group of students to write down what they meant by understanding an equation and sorted the responses into several thematic groupings, arguing that all the groupings should be taught. This approach is similar to the one adopted in this chapter.

Motivating the Study

In Sweden, the majority of undergraduate physics students have access to something called the *Physics Handbook* (Nordling and Österman 2006). This handbook details all the equations used in undergraduate physics courses along with physical constants and other salient information. Whilst this book is undoubtedly an extremely useful reference work, it does also lend itself to misuse. Following Redish (1994), students may be tempted to look upon the handbook as the ultimate collection of *dead leaves* – that is a complete set of ready-made tools for 'plug and chug' calculation.

The original idea for this study arose a number of years ago during stimulated recall interviews with Swedish physics undergraduates. The students were asked whether they felt they had understood their teacher's description of the de Broglie equation for matter waves $\lambda = h/p$ (where λ is wavelength, h is Planck's constant and p is the momentum of the particle). The students replied that they had indeed understood, and many noted that the equation itself was fairly trivial. However, when asked to identify the terms in the equation, it became clear that a large number of students did not know what the 'p' represented. How could these students say that they understood the equation, but not know what the individual terms represent? In their explanations the students rationalized their response by claiming that they 'could work that out'. It became clear that the students' idea of understanding the equation in this situation was judged in terms of whether they felt they could use the equation for numerical calculation. However, perhaps the most worrying aspect of this experience is that the students genuinely felt that they had understood the equation. It was not until they were asked a specific question about a variable that they noticed that they only had a superficial mathematical understanding of the equation.

In this chapter we argue that such situations should be expected in undergraduate physics. Recently, Eichenlaub and Redish (2018) suggested that physics students actually possess a wide range of strategies to help them understand equations, such as looking at extreme cases, estimating and using dimensional analysis. The problem, the authors argue, is that students do not always access these strategies when they would be productive.

Building on this experience, in this study we wanted to first document the range of ways that physics undergraduate students say they understand equations and then generate questions that could potentially be used together with the physics handbook to help students notice this range of ways of understanding equations.

Theoretical Framing

In this chapter we draw on diSessa's (1993, 2018) theory of *knowledge in pieces*. This is an epistemological perspective that views knowledge as '[…] a complex system of many types of knowledge elements […]' (diSessa 2018: 67). These knowledge elements or *pieces* are seen as dynamic and context dependent. Originating in physics education, the theory has been extensively used to offer new explanations of science learning phenomena. The knowledge in pieces approach suggests that we should not expect students (or even experts for that matter) to always display a conceptually coherent understanding across settings. Rather it is claimed that understanding consists of context-dependent *pieces,* where different ways of viewing the same phenomenon are cued in different settings. In this characterization, students develop expert-like understanding by making links between these separate pieces of knowledge and by gradually learning which 'piece' is appropriate for a given task. Drawing on this perspective, the research reported in this chapter attempts to document the range of different ways in which physics undergraduates in three countries say they understand equations. Having documented these different 'pieces' of knowledge, we then would like to help students notice these different ways of understanding equations.

Research Questions

To this end our research questions are as follows:

How do students in three countries say that they know that they have understood a physics equation?

What different disciplinary aspects of equations can be seen in an analysis of the aggregated set of answers to our first research question?

How might a more holistic view of the understanding of equations be communicated to students?

Methodology and Method

The Swedish data used in this study was originally collected as part of an *Introduction to Physics Education Research* course taught by the first author. Due to the time constraints of the course, a research design based on minimum input and maximized output was chosen. We asked undergraduate physics students in the USA ($n = 83$), Australia ($n = 168$) and Sweden ($n = 105$) the same simple question: *How do you know when you understand a physics equation?*

After being informed about the aims of the study, those students who agreed to participate wrote their answers to this question anonymously on blank sheets of

paper. The research followed the ethical guidelines of the Swedish Research Council (2011/2017).

Inspired by the phenomenographic notion of a 'pool of meaning' (Marton and Booth 1997: 133), our qualitative methodology treated the range of student answers in each country as single data sets. A central commitment of the phenomenographic approach is that humans experience phenomena in a limited number of discrete ways. However, unlike standard phenomenographic studies that would typically involve in-depth interviews to elicit different ways of understanding a particular phenomenon, in this study we were simply interested in documenting the range of ways in which students say that they feel satisfied that they have understood an equation (see Airey 2012, for an example of this type of analysis). Note that we were not trying to create an outcome space of logical relations between these ways of understanding as is often the case in phenomenographic analysis. Based on the reviewed literature and diSessa's (1993) theory of knowledge in pieces, we argue that if students believe they have understood an equation, they are unlikely to look for alternative ways of understanding it. Thus, we suggest that each of the ways that students express that they understand an equation represents a way of thinking about equations that students will need to leverage in certain circumstances.

Analysis and Results

Qualitative analysis involves 'working with data, organizing it, breaking it into manageable units, synthesizing it, searching for patterns, discovering what is important and what is to be learned, and deciding what you will tell others' (Bogdan and Biklen 1992: 145). In this type of work, iterative cycles are made through the data looking for patterns. Each cycle results in loosely labelled codings with temporary descriptors that may then be split up, renamed or amalgamated in the next iteration.

Our initial engagement with the data focussed on the Swedish data set, which had been written in Swedish. This first data set had been collected as part of an introduction to research course, where the course goals were to follow the process of qualitative research from the planning stage, through data collection and analysis, culminating in a presentation of results at the yearly university pedagogical conference. Joint coding of the data in the original language was carried out by the first two authors in the following manner. First we scanned the papers that the students had written their responses on and made a number of physical copies. Coding proceeded by first placing these copies into several piles where the answers seemed to be related. Next, the answers in each pile were read through, and we decided on a label or descriptor that summed up the pile. We adapted these labels as we went along. The reason we chose to initially work with the data in this seemingly old-fashioned, analogue manner rather than directly using qualitative analysis software was due to the requirements of the *Introduction to Physics Education Research* course that the work formed a part of. The aim was to both demystify the coding

process by making it visible and to *jointly* interact with the data in a form of legitimate participation (Lave and Wenger 1991). This first open coding resulted in 30 different descriptors (Table 1).

Below is an example of a student answer from the Swedish data set:

Jag upplever att jag förstår en ekvation inom fysiken när jag förstår tillämpningsområden, eller hur jag räknar med den och att jag vet vad den innebär för området. När jag själv också kan förklara det så att andra med någorlunda kunskapsnivå kan förstå så upplever jag att jag själv förstår.

English translation:

I feel that I understand an equation in physics when I understand the areas it can be used in, or how I can calculate with it and that I know what it means for the area of physics. Also when I can explain it so that others with a reasonable level of knowledge can understand—then I feel like I understand.

This particular student answer was initially coded under 6 of our 30 original descriptors:

– Can use it to get numbers/values.
– Know which physics problems it can be used to solve.
– Know the area of physics it belongs to.
– Know real-world areas it describes.
– Know which real-world problems it can be used to solve.
– Explain it to another person.

Later this particular student answer became a part of the *calculation, significance* and *explanation* themes that we describe in this chapter.

Table 1 The 30 descriptors from the first round of open coding of the Swedish data set

Solve real-world problems	Know the boundaries for using it
Can visualize it	Can verify it by experiment
Explain it to another person	Know the area of physics it belongs to
Know which real-world problems it can be used to solve	Know where it comes from historically
Can derive it	Can interpret results
Have derived it	Can identify the terms
Have seen someone derive it	Can draw a diagram
Know real-world areas it describes	Can draw a graph
Relate it to other concepts	Can rearrange it
Relate it to another equation	Can use it to get numbers/values
Link the equation to physical laws	Repetition
Use it to solve a physics problem	Can identify and understand the variables and constants
Know its status (law?)	Can recognize it
Know which physics problems it can be used to solve	Can read it
	Can remember it

Initially, we tried to make some sense of the 30 descriptors we had generated by thinking about how they could be related to one another, conceptualizing what we saw as links between them and visualizing these through linking lines. At this stage our work with the Swedish data was presented to the Uppsala Physics Education Research group. Our final diagram is summarized visually in Fig. 1, which was translated into English for the occasion. The three descriptors, *Remember it*,
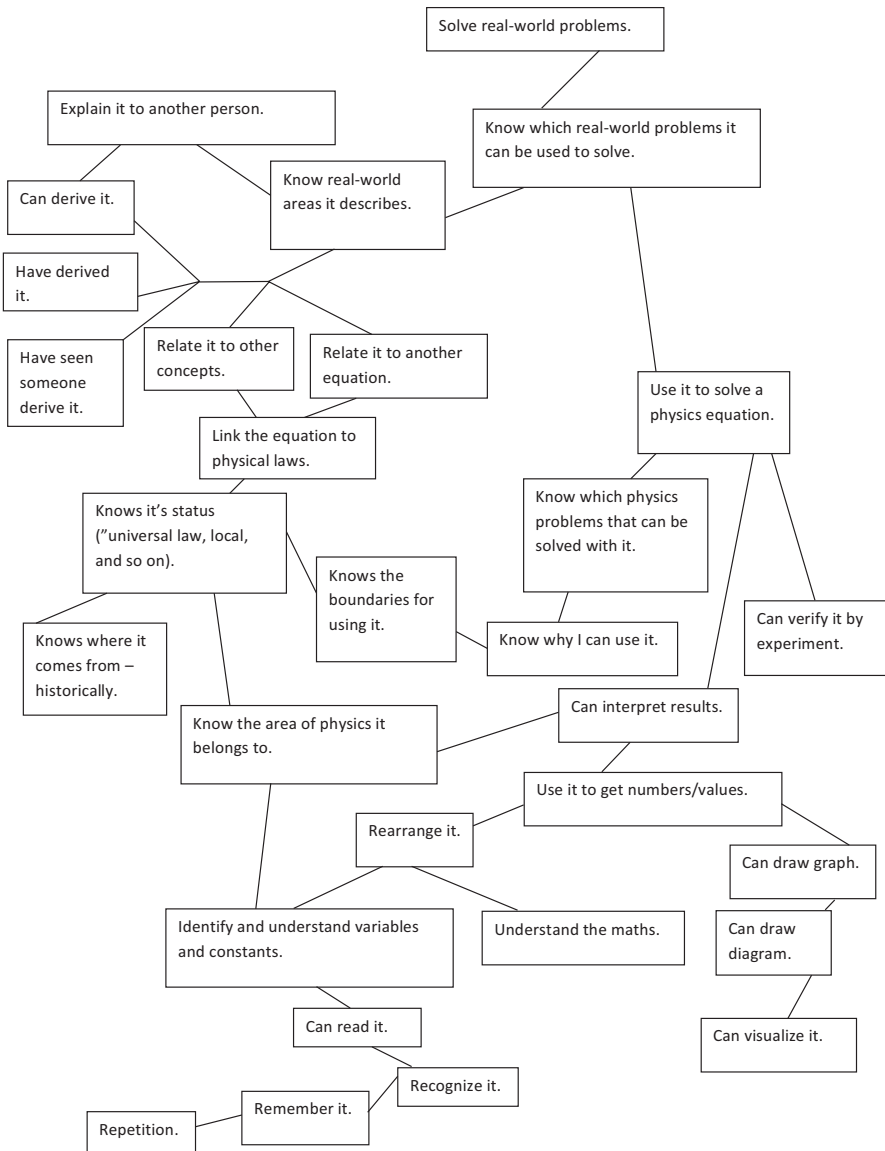

Fig. 1 The first attempt at linking the 30 descriptors derived from our initial open coding

Repetition and *Recognize it*, seemed to suggest that memorization and rote learning was important (cf. our earlier discussion of Redish's 1994 dead leaves model). The descriptor *Can visualize it*, whilst obviously important, seemed difficult to pin down without follow-up questions, and these were of course not possible due to our research design. We then amalgamated the 30 descriptors to make 13, before moving over to examine the US and Australian data.

We started this research project with the aim of working with a limited amount of Swedish data as part of an introduction to research course. We later expanded the scope with parallel Australian and US data with the intention of documenting differences across three quite different countries. Here, we were hoping to be able to infer educational reasons for any differences that we found. However, in our analysis it was the very similarity of the three data sets that was most striking. It quickly became apparent that there was a range of answers that repeated across countries. So, although we started out looking for differences that we could then attempt to link to the different educational settings, we ended up being surprised by the similarity of answers across the three groups. All of the codings that we had found in the Swedish data could also be readily identified in the US and Australian data, and no new codings were identified.

On the whole, there were also similar proportions of answers across the settings (the one difference that we could see was that students in the US data set were more likely to mention derivation as one of the ways that they used to judge whether they understood an equation). The similarity in answers across the three countries led us to abandon our intended comparative approach and treat the answers from the three countries as a single data set insomuch as we used the same coding system for all three data sets.

At this stage we transcribed all three data sets placing them into separate excel files. The first two authors then separately recoded all three data sets using the 13 themes. Despite the work we had done in reducing the original 30 codings to 13, we realized during this recoding process that some of the themes were in fact quite similar to each other and had considerable overlap (in such cases we noticed that answers that we coded as one of category were almost always also coded as a second category as well). We therefore restructured our categories to create our final list of ten categories. Individual coding of all the original responses into these ten categories had an inter-rater reliability of 74% for the American data set, 78% for the Australian data set and 88% for the Swedish data set. Note here that each student answer was usually assigned to a number of categories and the inter-rater reliability takes into account *any* discrepancies in the two codings. Thus if one coder codes one student answer under four categories and the other coder codes the same answer under five categories (the same four plus one) this will lead to one discrepancy being counted. Taken together, our measures of inter-rater reliability suggest to us that the coding system was very reliable indeed.

The ten themes are Significance, Origin, Description, Prediction, Parts, Relationships, Calculation, Explanation, Repetition and Memorization. In what follows we explain each of these ten themes we identified by briefly illustrating them

with three quotes from the data. (Note that quotes from the Swedish data set have been translated.)

Significance
This theme deals with knowing why, when and where to use an equation.
Essentially knowing when and where to use it and when not to use it.
To be able to use it in the right place and knowing what you are calculating and getting out of that formula.
Understanding is knowing why we use it, when it applies and how to modify for a given circumstance.

Origin
This theme involves understanding where the equation comes from in terms of derivation and the equation's historical roots.
When the equation is derived in distinct, clear steps from basic easily understood models.
When you can derive it!
Understand – know background information – history of formula know concepts that were used as a base for this.

Description
This theme involves being able to visualize the equation and to be able to link it to a real life situation or experiment.
Diagram is very helpful tool to understand it.
I only really understand when it has been shown experimentally to me.
When I can visualize it.

Prediction
This theme involves using the equation to predict the behaviour of a system.
When I can use it to predict how a physical system will develop over time.
Made accurate predictions about outcomes.
When I can use it to predict the behaviour it is describing.

Parts
This theme involves being able to manipulate an equation and understanding its different terms.
When you know what all the variables and constants mean.
Understanding a formula means you can rearrange it and use it in any format.
Understanding means understanding the relationship between the variables.

Relationships
This theme involves making links to other equations or constructing it from other equations.
When I can connect it to equations I've met before.
Understand the concept behind it and be able to use it to construct other formulas.
Knowing how other formulas can be derived from the formula.

Calculation

This theme involves using the equation to solve physics problems.

When I calculate and get the right answer.

Understanding is knowing how to use it to solve a problem.

Know how to apply it to solve real problems.

Explanation

This theme involves being able to explain the equation to someone else.

To understand it you should be able to explain how it works and is applied.

When I can explain it to a ten year old.

When you can explain it to your grandmother.

Repetition

This involves students using an equation repeatedly.

Understand: I've used in multiple applications over time.

It takes a while but in the end I usually understand after I've seen it and used it a number of times.

You practice many times until you have a complete understanding of the context/ concept behind what the question is asking.

Memorization

This theme involves being able to recall the equation.

To understand is to be able to recall it and apply the formula to problems.

Understand – memorized and know when to use it.

A good sign that I understand an equation is when I can remember it.

Of these ten themes, it is only the first eight that we focus on going forward, since we feel that the final two themes, *Repetition* and *Memorization* potentially encourage rote learning of physics equations, which has been shown to be coupled to surface rather than deep understanding (Marton and Säljö 1976; Chin and Brown 2000).

Following diSessa's (1993, 2018) theory of knowledge in pieces, we suggest that each of the remaining eight themes represents a different disciplinary aspect of student understanding of physics equations. We argue that together the different aspects represent a more holistic view of physics equations that we would like all our students to experience. This led us to try to operationalize our findings to help students notice the different themes we had identified.

Creating the Questions

Based on our findings, we wondered how best to highlight this more holistic view of how students think about equations. This prompted us to return to the original data and think about what might help students to discern the range of aspects we had

identified. We decided to attempt to write a set of questions that reflected the original data with respect to the eight themes. In order to do this, we returned once again to our original three data sets and tried to construct questions for each of the themes that also summarized what the students had originally told us. This process resulted in the questions for each theme that can be seen below:

Significance: Why, When, Where
Do you know why the equation is needed?
Do you know where the equation can and cannot be used (boundary conditions/
    areas of physics)?
Do you understand what the equation means for its area of physics?
What status does this equation have in physics (fundamental law, empirical approxi-
    mation, mathematical conversion, etc.)?

Origin
Do you know the historical roots of the equation?
Can you derive the equation?

Description/Visualization
Can you use the equation to describe a real-life situation?
Can you describe an experiment that the equation models?
Can you visualize the equation by drawing diagrams, graphs, etc.?

Prediction
Can you use the equation to predict an outcome?

Parts
Can you describe the physical meaning of each of the components of the
    equation?
How does a change in one component affect other components in the equation?
Can you manipulate/rearrange the equation?

Relationships to Other Equations
Can you relate this equation to other equations you know?
Can you construct the equation from other equations that you know?

Calculation
Can you use the equation to solve a physics problem?
Can you use the equation to solve a physics problem in a different context than the
    one in which it was presented?
When you use the equation to calculate an answer, do you know:
How your answer relates to the original variables?
The physical meaning of this answer?
Whether your answer is reasonable?

Explanation
Can you explain the equation to someone else?

We suggest that this set of questions could be used when students meet a new equation. We argue that either asking oneself these questions or better still, discussing them as a group could potentially help students to focus on different aspects in their understanding of physics equations.

Discussion and Conclusions

Our first research question for this chapter was:

How do students in three countries say that they know that they have understood a physics equation?

Here we were surprised to find a range of responses that repeated across the three countries. *We found no noticeable differences in the range of answers students gave across the three countries, which led us to treat all the answers as a single 'pool of meaning'* where we sorted all three data sets using the same coding system. Drawing on Bernstein's (2000) categorization of university disciplines, one possible reason for this similarity in answers across settings could be the *hierarchical* nature of knowledge in physics. Essentially in Bernstein's view, disciplines with hierarchical knowledge structures demand that new knowledge should be compatible with what is already known. This leads to a largely agreed view of what constitutes knowledge for this type of discipline. In this respect, Bernstein suggested that physics was the most hierarchical of all disciplines (see Airey and Larsson 2018 for a discussion of Bernstein's ideas with respect to physics education).

Our second research question was:

What different disciplinary aspects of equations can be seen in an analysis of the aggregated set of answers to our first research question?

Here we identified eight themes that signal different disciplinary aspects of physics equations: Significance, Origin, Description, Prediction, Parts, Relationships, Calculation and Explanation.

Note that we do not claim that this is a definitive list of what it means for a student to understand a physics equation, rather we simply note that these themes could be noticed in our aggregated data. We do, however, claim that these themes represent a more holistic view of physics equations. Based on this work and diSessa's (1993) knowledge in pieces, we further argue that students who meet a new equation may only focus on a few of the themes we have identified and fail to notice other aspects.

Our final research question was:

How might a more holistic view of the understanding of equations be communicated to students?

Here we made a methodological decision to try to capture the essence of what students were describing by writing a set of questions. Our purpose here was to

attempt to help students who *think* they have understood an equation to notice further aspects that they may have overlooked.

Our questions are based on student-generated, self-reported data. Potentially physics experts could experience physics equations in even more complex disciplinary ways. Indeed this actually appears to be the case. For example, Eichenlaub and Redish (2018) describe the role of extreme cases, dimensional analysis and estimation in the understanding of physics equations. Although aspects of these three roles can be identified in our data, they are not explicitly teased out in our findings. We suggest that this is due in part to the nature of the original question we asked students that was not grounded in a particular problem.

In continuing work we are asking the same question to a cohort of physics lecturers in the hope of identifying more sophisticated ways of understanding. We are also trialling the themes and related questions that we generated in various teaching situations. Here we are interested in whether students perceive the questions as helpful in their learning.

In undergraduate physics we suggest that what it means to understand physics equations is tacitly communicated to students through the types of problem-solving they are asked to do. For example, in their discussion of multimodality in science education, Airey and Linder (2009: 42) argue that 'the traditional method of examining science courses through problem-solving and calculation may lead to students passing examinations without appropriately experiencing the ways of knowing of the discipline'. We argue that we need to help students to begin to see equations in a more holistic, expert-like manner that entails much more than seeing them as tools for calculation. In this chapter we propose making this hidden curriculum explicit and have offered a set of questions that can be used to start this process.

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Affordances and Constraints of Learning Progression Designs in Supporting Formative Assessment

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Introduction

Learning progressions – representations of the sequential development of student ideas and scientific practices within core content domains (Corcoran et al. 2009) – have been the focus of much research in science education in recent years (Duschl et al. 2011). The field is only beginning to understand how learning progressions can serve not only as tools to support teacher design of classroom assessments (Briggs and Peck 2015) but also the extent to which use of a learning progression can support teachers' ability to interpret and respond to student ideas (Furtak et al. 2016). Questions have been raised about the underlying assumptions of learning progressions as hypotheses about student development (Alonzo and Elby 2014), as well as the extent to which teachers actually use the information progressions contain in their teaching practice (Alonzo and Elby 2015). For example, do progressions that represent student understanding in an ordered and linear manner from "novice" to "expert" help teachers diagnose student thinking more effectively than progressions that list "knowledge in pieces?" (Smith et al. 1993). How do different structures to learning progressions (Wilson 2009) support teachers in different ways?

This paper analyzes data from 1 year of a research-practice partnership (Penuel et al. 2011) that sought to determine the affordances and constraints of different forms of learning progressions in supporting teachers' formative assessment design.

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241

Background

Learning Progressions

Learning progressions in science are representations of hypotheses about the pathway – or pathways – that students are likely to follow as they learn about disciplinary core ideas and practices (Corcoran et al. 2009) and are anchored on one side by "what is known about the concepts and reasoning of students entering school" (NRC 2007: 219) and at the other end by what society expects students to understand about science. The middle spaces suggest various intermediate understandings. Learning progressions have been created for a variety of grain sizes, from student learning that might occur over a few weeks or months (e.g., Yin et al. 2014) to those spanning multiple years and grade bands (e.g., Lehrer and Schauble 2012). Some integrate scientific practices along with content (Songer and Gotwals 2012). That said, however, there remains a considerable amount of variation among what constitutes published learning progressions. Several scholars have suggested frameworks describing different types of learning progressions, including Shavelson (2009), Wilson (2009), and Duschl et al. (2011).

Shavelson (2009) differentiated between progressions that represent content sequences for units of instruction, such as those that look at the development of understanding across grade bands or the entire K-12 spectrum. The learning progressions that underlie the Next Generation Science Standards [NGSS] in the United States (Board on Science Education 2012) are a recent and prominent example of this sort of progression. These progressions differ from those derived from empirical research and modeling of student response patterns and plot out pathways of how student understanding develops from novice to expert in particular contexts. Duschl et al. (2011) called this type of progression *validity* progressions, where particular ideas are expected to be replaced over time with more accurate ideas. Evolutionary learning progressions, in contrast, identify the stepping stones and developmental pathways of students as they develop their understanding of a given phenomenon or practice (Duschl et al. 2011). Wilson (2009) focused on the interrelationships between the levels of different constructs (Wilson 2005) in learning progressions.

Given these different typologies for learning progressions, it is not surprising that there is also not a single, accepted approach for evaluating the validity of a learning progression framework. A central question about learning progressions as hypotheses about the development of student understanding and engagement in practice is the extent to which they accurately capture the nature and development of student thinking in a given domain. This question is difficult to answer, however, given that learning progressions are usually not viewed as being "developmentally inevitable" but rather pathways that students may be likely to follow given exposure to a particular series of learning experiences (hence, Shavelson's emphasis on "instruction" in both categories of learning progressions that he describes). In that sense, a learning progression may never be completely "right" or "wrong."

Instead, we propose an alternative perspective, one based upon pragmatic philosophical perspectives (Menand 2002) that have informed educational research designs (e.g., Howe and Eisenhart 1990). The pragmatic perspective rejects philosophical dualisms as false (in this case, that the underlying hypothesis of a learning progression is either right or wrong) and rather suggests that a solution should meet the standard of being useful given a particular context or situation (Johnson et al. 2014). From this perspective, then, a learning progression should not need to meet the standard of being "right" in the sense that it is ever possible to find the one real big-T "Truth" through empirical research.

A more fruitful approach might be to study the extent to which a learning progression is useful or facilitates insights relative to a particular purpose in a given context. For example, a learning progression might be useful for a research team working to define the parameters of a concept or practice for the purpose of designing a diagnostic assessment (e.g., Alonzo and Steedle 2009) or as the foundation for a process of curriculum design (e.g., Mohan et al. 2009). Alternatively, a learning progression might guide the work of teachers planning and reflecting on classroom assessments (e.g., Furtak and Heredia 2014) or for teachers listening to and interpreting student ideas in the course of classroom practice (e.g., Berland and McNeill 2010; Furtak 2012). It might also organize the design and conduct of a series of professional learning experiences for teachers (e.g., Thompson et al. 2009).

Each of these uses is specific to a particular context; therefore we do not suggest that a learning progression developed for a particular use, such as curriculum design, may immediately have the same utility in another context. Instead, each learning progression might be considered useful for the purpose and context for which it was developed, and the authors and users of the learning progression thus must articulate and interrogate their own criteria for determining the utility of a learning progression in the context in which they are using it or the context in which they intend it to be useful. We turn to a particular context for learning progressions in the next section.

Formative Assessment

Formative assessment as a phrase refers to the tasks or activities that students complete in classrooms as well as the processes or practices in which those students engage as they share and attend to each other's ideas (Bennett 2011; Furtak and Heredia 2014). Among the many contexts in which learning progressions might be used is to support teachers in cycles of formative assessment task design. Formative assessment is most often conceived as the process by which teachers set learning goals prior to instruction, elicit student understanding relative to those goals, and then interpret student responses and provide feedback to move learners forward toward those learning goals (e.g., Black and Wiliam 1998).

The argument for using learning progressions to support teachers in formative assessment design proceeds according to the following logic: by representing the ways student ideas develop in a domain, progressions may be ideally suited to

support teachers who may have limited experience with the topic (Bennett 2011). In this sense, a learning progression is a kind of map that represents the complex terrain of student thinking within a domain and can help teachers set learning goals and design formative assessment tasks to elicit student ideas relative to those goals. In addition, Bennett (2011) argued that a learning progression could help teachers distinguish between the different types of ideas that students may commonly experience as they learn; in a sense, serving as an interpretive framework for teachers as they look at and plan ways they might respond to student ideas (Furtak 2012). Heritage et al. (2009) suggested that learning progressions might help to concretize the "next steps" part of formative feedback that can be so elusive to teachers.

Messick (1989) defined validity as the result of a process of induction of the evidence for and the consequences of the interpretation and use of information from assessments. From this perspective, a validity argument might be constructed for a given learning progression to support formative assessment as described above if it were to provide support for teachers to learn about student ideas, identify learning goals, design formative assessment tasks, and to interpret student ideas for the purpose of identifying next steps for instruction.

Teachers could use a learning progression, for example, to evaluate the scope and sequence of their instructional units, identifying productive points in the curriculum where an assessment would be useful before proceeding. The progression could be used to identify particular types of student ideas that teachers might want to look for, and then teachers could deliberately design the formative assessment to surface these specific ideas. When using the assessment with students, the learning progression could also serve as a framework for listening to student ideas, and teachers could use the progression to identify or categorize those ideas, either in real-time or in meetings with colleagues in which they looked together at student work (Furtak 2012). Then, teachers could consider possible feedback that would be targeted to move students up the progression, step by step.

Constraints and Affordances of Learning Progression Designs for Formative Assessment: A Pragmatic Perspective

In this paper, we examine the extent to which a series of learning progressions with different designs and intentions supported high school science teachers in designing and interpreting student responses from formative assessment tasks. Specifically, we respond to the following question: *How can different types of learning progressions support teachers' formative assessment task design and interpretation of student ideas?*

Method

This paper draws on data collected as part of a larger study, funded by the National Science Foundation, that has explored the influence of learning progressions on teacher and student learning in high school science. We use an embedded case study approach (Yin 2003/2018) to analyze the ways in which different learning progressions supported teacher formative assessment task design and interpretation of student ideas. The data analyzed in this paper are drawn from an initial, exploratory phase of the project in which we facilitated teachers' bimonthly meetings in their school-based professional learning communities to plan formative assessments and reflect upon enactment of those assessments, using learning progressions as a resource across this process.

Learning Progressions Used in This Study

After performing a review of published learning progressions, we identified candidate learning progressions and representations in each content domain that met the following criteria: (1) focused on core conceptual domains addressed in the curricula in use for 9th grade Physics, 10th grade Chemistry, and 11th grade Biology in our partner school district, (2) originally developed for or to include the high school grade band, and (3) linked to existing assessments. The six learning progressions we ultimately used are represented in Table 1.

Table 1 Learning progressions

Content area	Learning progressions	Grade band	Design features
Physics	Force & Motion (Alonzo and Steedle 2009)	Top level 8th grade	Unidimensional; integrates common errors
	Energy (Neumann et al. 2013)	6–10	Multidimensional
Chemistry	Atomic structure of matter (Minstrell n.d)	9–12	Facet clusters
	Changes in matter (Minstrell n.d)	9–12	Facet clusters
Biology	Natural Selection (Furtak and Heredia 2014)	10	Multidimensional; integrates common misconceptions
	Matter and Energy Cycling in Socio-Ecological Systems (Mohan et al. 2009)	5–10	Multidimensional; levels go from macro- to micro-level interactions

Professional Development Intervention

A university-based facilitator met with each learning community twice monthly to introduce the learning progressions, guide the process of formative assessment task design, and provide structure as teachers interpreted student work and identified next instructional steps. The meetings were roughly guided by the Formative Assessment Design Cycle (FADC; Furtak and Heredia 2014) a five-step process that supports teachers in the development of formative assessment tasks with the support of a learning progression. The cycle begins with facilitators walking teachers through the learning progression to *Explore Student Thinking*, using the learning progression to learn about student thinking in the target domain and to identify learning goals. Next, teachers identify ideas on the learning progression that they would like to assess during their instructional units, and *Design Tasks* to specifically elicit those ideas. Then, teachers *Practice Using Tasks* by using the learning progression to anticipate the different ways students might respond to the task and rehearse the types of feedback they would provide to different types of ideas (Horn 2010). The fourth step has the teachers *Enact Tasks* in their own classrooms. Finally, teachers come back together to *Reflect* on classroom enactment by looking at student work together and using the learning progression to interpret and categorize groups of student responses and plan feedback to move students forward in their learning. This feedback is discussed in multiple time frames (Wiliam 2007), such that teachers identify not only what they will do in the next class session but also how they will draw upon this information to support students for the rest of the unit and academic year. At the same time, teachers reflect upon the nature of the formative assessment activity itself, identifying the extent to which it helped them elicit student ideas on the learning progression and how it might be improved and revised for the next year.

Participants

This study is embedded in a multiple-year research-practice partnership (Penuel et al. 2011) between researchers at the University of Colorado Boulder and the science curriculum coordinators and teachers in a large socioeconomically, linguistically, and ethnically diverse school district located in the western United States. As part of the study, researchers from the University of Colorado regularly visit and facilitate content-specific professional learning community meetings (McLaughlin and Talbert 2001). Participants were recruited from three high schools in the district (HS 1, HS 2, and HS 3), with between 3 and 5 teacher participants in each learning community at each school). The teacher participants in this study are summarized in Fig. 1.
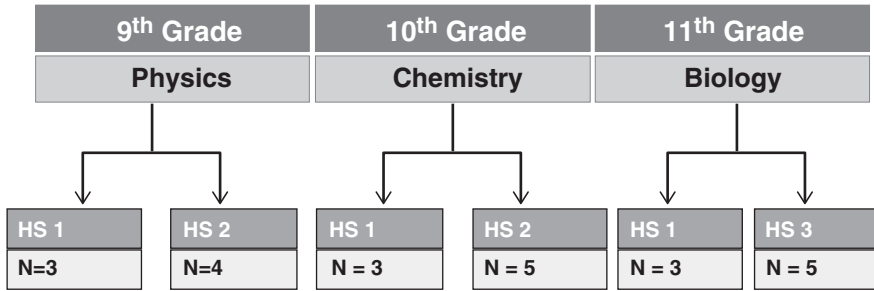
9th Grade	10th Grade	11th Grade
Physics	Chemistry	Biology

HS 1	HS 2	HS 1	HS 2	HS 1	HS 3
N=3	N=4	N = 3	N = 5	N = 3	N = 5

Fig. 1 Study participants by grade level, content area, and school

Sources of Data

Our research question focused on the ways that teachers designed formative assessment tasks and interpreted student responses in professional learning community (PLC) meetings. We studied how teachers made use of the learning progressions throughout four phases of the FADC, including Explore Student Thinking, Design Tasks, Practice Using Tasks, and Reflect. Our work with teachers was located in their PLC meetings, and we did not focus on how teachers used (or did not use) learning progressions during the enact phase. Our sources of data include copies of teacher learning community meeting agendas, learning progressions (in both their original and, in some instances, modified formats), copies of teacher-designed formative assessments, and copies of student work. We also conducted end-of-year interviews with teachers in which we explicitly asked them about their impressions of the learning progressions the extent to which they supported them in the FADC. Finally, we kept notes on our decisions as we made changes to the learning progressions to make them more accessible to the teachers participating in the project.

Analytic Approach

Learning Progressions We drew on the frameworks presented above to analyze and summarize the design and original contexts of use for the learning progressions in Table 1.

Field Notes To understand the ways in which each teacher learning community used the different learning progressions, we created an analytic memo format based on an implementation checklist for the FADC (Furtak et al. 2016) that allowed us to track when and how each learning community used each learning progression to support formative assessment task design and student work interpretation. We applied this analytic process to memos from each PLC meeting. As we engaged in

this process, we developed a set of grounded codes that captured the ways that teachers discussed and used the learning progressions in the meetings.

The research memos were then used to create an aggregate representation that mapped our emergent propositions about the ways that learning progressions were used to support teachers as they engaged in different aspects of formative assessment task design and interpretation of student ideas in their PLC meetings: exploring student ideas, designing formative assessment tasks, interpreting student ideas, and planning feedback for students and instruction. This aggregate representation helped us to summarize, across schools and learning progressions, the different ways the progressions were used during the 2016–2017 academic year, as well as to highlight different aspects of the different learning progressions that are related to the ways teachers used them.

Interviews We also analyzed transcripts of the teacher interviews by applying the same grounded codes focusing on contexts of teacher use of the learning progression. As a check for validity and reliability in this process, the second author first analyzed the transcripts from one school, developing propositions supported by an audit trail of data sources. These propositions were then shared with the first author, who independently examined the data. The second author then further analyzed teacher interviews across all participating schools. Propositions were then further interrogated by members of the research team.

Results

Our analyses of the use of the six different learning progressions across the learning communities at our three partner schools indicate uneven areas of use to support setting learning goals, designing formative assessment tasks, interpreting student work, and planning feedback. In this section, we begin with an analysis of the original contexts of use of the six learning progressions we analyzed and then present the results of our analyses according to these contexts of use. We evaluate the relative validity of these learning progressions in these contexts of use and then identify three emergent design criteria for learning progressions to support formative assessment task design and interpretation.

Original Learning Progression Designs and Purposes

The six learning progressions that we brought to the teachers at the outset of the study were designed for different contexts of original use.

In 9th grade *Physics*, we worked with two well-known learning progressions. The Alonzo and Steedle (2009) progression for Force and Motion was originally developed to support the diagnosis of student ideas with ordered multiple-choice

items. The second progression we worked with is the Neumann et al. (2013) progression for Energy, which was also developed as a basis for the design of a diagnostic assessment.

In 11th grade *Biology*, we worked with the Mohan et al. (2009) learning progression for Carbon and Energy Cycling in Socio-Ecological Systems. This progression was originally designed to guide construction of the Carbon Time curriculum for students in upper elementary through high school. We also used the Elevate series of learning progressions, which was originally designed to guide high school teachers' formative assessment design and enactment in a previous study (Furtak and Heredia 2014). The upper anchors of the Elevate progressions represent a scope and sequence for a high school unit on Natural Selection and individual construct maps attempting to track the development of student ideas across time.

In 10th grade *Chemistry*, we used the ChemFacets (Minstrell n.d.), which organize sets of student ideas into groupings called facet clusters without identifying specific trajectories for the development of those ideas. The ChemFacets were designed for use with the Diagnoser software, an online, diagnostic assessment system for classroom use that generates reports intended to inform teachers about their students' ideas and to provide suggestions to inform instruction.

Contexts of Teacher Use of Learning Progressions

Setting Learning Goals and Exploring Student Ideas   Teachers used the learning progressions to identify areas to emphasize in their existing curriculum materials, and conversely (e.g., with the Force and Motion learning progression), they used their curriculum materials and standards documents to select areas of the larger progressions to focus upon (e.g., Natural Selection). During interviews, teachers commonly referenced the ways in which learning progressions informed their unit planning (e.g., a biology teacher described, "We used the evolution [Natural Selection learning progression]… where it showed us how it would develop over time and I mean, really we just kind of made a list of what were the big ideas").

Across all of the content areas, the learning progressions were also used as frameworks for describing, articulating, and naming common student ideas or – as they were sometimes called in the meetings – misconceptions within the domains at hand. The ChemFacets, for example, were described by the teachers as a list of misconceptions and a starting point for planning their units, although teachers noted that the ideas were not aligned with their *Active Chemistry* (Eisenkraft 2003) curriculum. Similarly, the Energy learning progression helped teachers to identify common student misconceptions about energy.

To a lesser degree, at some schools, the learning progressions were used to support teachers as they defined scopes and sequences for their unit design. For example, at HS 3, biology teachers used both the Carbon and Energy Cycling and Natural Selection learning progressions to develop unit scopes and sequences, although the

teachers relied more heavily on other resources including their curriculum materials and standards documents.

For the physics PLC at HS 2, teachers noted that the Force and Motion learning progression was a challenge to use with their *Active Physics* (Eisenkraft 2010) textbook because *Active Physics* spiraled back to concepts it contained multiple times within the school year. Additionally, while the Energy learning progression had a more linear sequence, the teachers at HS 2 also noted potential curriculum misalignment between the Energy progression and their *Active Physics* curriculum.

Across most of these instances, however, we noted that it was usually the facilitator in PLC meetings, not the teachers, who continually brought up the learning progressions and described how they could support unit planning and understanding of student thinking. In end-of-year interviews, teachers described the learning progressions as providing a "menu" of possible student ideas that might come out during instruction and helping them to understand different types of ideas but did not make sustained or deep references to the progressions.

Designing Formative Assessment Tasks   Our intention was for teachers to use the learning progressions to design formative assessment tasks after they identified student ideas they wanted to elicit that were aligned with their curriculum materials at particular points during instructional sequences. However, our analyses of field notes indicate that while teachers did design formative assessment tasks as part of their PLC work, the learning progressions were not used as an explicit part of this design process in any PLC meetings with the small exception of biology PLC meetings at HS 3.

When working with the Natural Selection and Carbon and Energy Cycling learning progressions with biology teachers at HS 3, facilitators referenced the learning progression to discuss the purpose of formative assessment design to elicit student ideas that then might be interpreted and provided feedback with the learning progressions. These teachers developed a formative assessment activity by adapting questions from an assessment linked to the Carbon and Energy Cycling learning progression that was shared by the university facilitators. However even with biology teachers at HS 3, the learning progressions still did not play a central role in designing formative assessment tasks.

Interpreting Student Ideas   After teachers used formative assessment tasks with students, they brought student work back to their PLC meetings where we intended to support teachers in using the learning progressions as a guide to interpret student work. However, teachers found it easier to develop their own systems of sorting student ideas rather than forcing student work into categories in the progressions. At HS 3, one biology teacher even brought a printout of the Carbon and Energy Cycling progression to the meeting where we intended to look at student work and said that she had attempted to use it to interpret student work but quickly abandoned it. At the meeting, along with the other teachers in this PLC, she instead generated her own categories that emerged from patterns of student thinking she observed in the work herself. Similarly, the Chemistry teachers made notecards that they titled with patterns they had identified in the student work rather than using ChemFacets to explic-

itly identify student work, and the Physics teachers made piles of student work without the learning progression as well.

One Chemistry teacher at HS 2, however, who was new to the teaching profession, described how she had experienced changes to the way she enacted her units based on working with the ChemFacets, stating in an interview that "It was comforting to see that this is what the kids have to know, these are the common misconceptions." This response indicates that learning about the student ideas represented in the facet clusters had provided her with a conceptual resource that structured her interpretation of ideas. This explicit reference to a progression influencing classroom enactment was, however, the exception and not the rule across the teachers and PLCs.

Planning Feedback for Students We also intended that teachers would use the learning progressions to support discussions and planning for next steps for instruction and generate helpful feedback that might be provided to students to help them advance in their learning. In-depth conversations around next steps for instruction on the basis of the learning progressions were unfortunately rare, despite the presence of facilitators trying to emphasize these conversations. While teachers sometimes discussed generic next steps for instruction, only in the case of the HS 2 Chemistry PLC did this conversation get specific to actions from information about student ideas in the progression. In this instance, teachers had talked about anthropomorphizing atoms, one of the facet clusters in the Atomic Structure ChemFacets, and discussed changes to their instruction they might make in the next academic year to better address these ideas. Even at HS 3, where biology teachers had used an assessment item that was directly linked to the Carbon Time learning progression, teachers did not attempt to interpret student response patterns in line with the levels of student ideas on the learning progression and ultimately created their own patterns of student responses.

A notable exception, however, was in the instances where teachers were using learning progressions in PLCs to support interpretation of assessments linked to the learning progressions that had been administered by the researchers. In these instances, rather than interpreting co-designed formative assessment tasks, teachers were working with assessment items that were developed by the original designers of the learning progressions (Force & Motion, Alonzo and Steedle 2009; ChemFacets, Minstrell n.d.), and these meetings centered around discussions of researcher-prepared score reports that were explicitly linked to the learning progressions. At HS 2, the first of these meetings across the project, the conversation was at first a challenge because the physics teachers did not have the prior necessary understanding of the learning progression; a redesign of the score reports and facilitation process led to a more successful meeting with physics teachers at HS 1 several weeks later (Henson et al. 2018).

At HS 1, the Chemistry teachers engaged in deep conversation around the ChemFacets, naming specific facet clusters by number as they interpreted the score report. These findings, although not specifically related to the co-designed formative assessments, do suggest that a close link between the learning progression and

assessment items accompanied by reports that draw clear links to the learning progression facilitated deeper use of learning progressions with conversation around student ideas and next instructional steps.

Design Features Conducive to Formative Assessment Design, Enactment, and Reflection

As we reflect back across the schools and PLCs, it is clear that our intention to use the learning progressions to support formative assessment task design and interpretation was not realized as we had intended. Our field notes indicate efforts on the part of the facilitators to introduce the learning progressions and to use the learning progressions, but these resources were not ultimately a major focus of the co-design or interpretation of formative assessment tasks in the PLC meetings.

This outcome likely stems from the large difference between the context of the original design and use of the learning progressions, which we detail in section "Original learning progression designs and purposes", and the use of the learning progressions in our partner district to support formative assessment task design and interpretation. Only the Natural Selection learning progression was originally designed for this purpose and then again in a different school district using different curriculum materials. Clearly the difference in context mattered, as noted by several of the teachers. However, we did observe several instances in which the learning progressions were used, either across several PLCs or in a sustained way by one individual.

Discussion

Constructing a Validity Argument from a Pragmatic Perspective

As we conclude, we return to the pragmatic perspective for the validity of these progressions for this context of use presented earlier in this paper. The preceding analysis suggests that we can only conclude that the progressions were more valid for use in supporting teacher discussions about unit scope and sequence, as well as learning about the range of student ideas in the content domains the progressions covered, than they were for supporting formative assessment task design. The progressions were also not immediately useful to teachers in interpreting student work or identifying next steps for instruction for the formative assessment tasks designed in their PLCs, although the progressions were more informative when teachers were discussing score reports presenting student response patterns to items directly linked to the progressions. To a certain degree, these findings are perhaps not surprising, given that each of these progressions has been migrated out of the various contexts of their original use.

Design Criteria for Learning Progressions for Formative Assessment

As we look across the different progressions, which had different features, we did identify three categories of design criteria that appeared more useful to teachers as they designed formative assessment tasks and interpreted student ideas. We describe each of these below.

Match Between Assessments and Learning Progressions The instance in which we gained more traction with the learning progressions was not even in an instance of designing formative assessments but when teachers were using the learning progression to interpret student response patterns on assessment items designed alongside the learning progressions themselves. While this was not always the case in our findings, this result suggests that a good fit between the assessment task and the learning progression, along with facilitation resources such as a score report linked to the learning progression, may be more likely to lead to conversations in which teachers engage with the learning progression more substantively.

These missing resources are reflected in an interview with one of the biology teachers at HS 3, who noted the challenge of not having specific lesson resources to connect to the learning progression, noting that he felt the progression needed "… to be put in context of a lesson that would be delivered and tied to it so that there is a clear lesson formative matching. If you have the formative but there's no lesson attached to it, then you're going to have to cobble together a lesson."

Grain Size The majority of the learning progressions we have used in the study were large enough to span multiple years of student learning; as such, teachers were often unsure where to begin in using the progressions to diagnose student thinking. In the case of biology at HS 3, teachers worked with one progression that spanned all grades from K-12 (Carbon and Energy Cycling) and a second progression that covered only one high school unit in one grade level (Natural Selection). When asked about these two learning progressions, teachers found the latter more useful for the formative assessment design work they had done in our project.

One Chemistry teacher, working with a ChemFacets cluster for the structure of matter, found that it contained so many ideas that he did not find the representation useful to support his formative assessment design or classroom practice. This had to do with the *amount* of ideas covered, though, and not the span of a curriculum (e.g., spanning ideas covered in multiple grade levels) that might be represented in other progressions. Indeed, another Chemistry teacher said that the same facets had helped her have an organizing framework for student ideas as she was teaching.

Teacher Ownership Across our analyses, it was clear that the learning progression was just one of several resources that teachers used while planning units and formative assessments. They also used district-prioritized standards documents, unit pacing guides, textbooks, and other curriculum materials. A biology teacher called one of the learning progressions the "one that you guys showed us," perhaps

reflecting that the learning progression was something we were bringing and not something that was owned by the teachers.

In most of the PLCs, teachers ultimately created resources that were more useful to them – their own local scopes and sequences and their own systems for identifying and sorting student ideas – rather than using the ones we had brought to them. These results suggest that some kind of hybridized model of progression, one that incorporates ideas from the research-based learning progressions, in addition to those building on the resources teacher bring, might ultimately be better – and more valid – supports for teachers as they design and interpret student ideas from formative assessments.

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Learning Progressions and Competence Models: A Comparative Analysis

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Introduction

In many countries, current goals for science education are described in terms of performance expectations or competences, rather than lists of content students should learn (Koeppen et al. 2008). Models of student learning describe the performances that might be expected as students work toward a set of these expectations or competences in a given domain. These models have the potential to inform educational objectives, curriculum, instruction, and assessment (e.g., Gotwals 2012; Reusser 2014). As such, they may mediate between standards, educational objectives, teaching activities, and student learning. Thus, they may support the attainment of educational goals by guiding teachers' diagnoses of individual student learning (e.g., Terzer et al. 2013) and, hence, instruction that is tailored to students' learning needs (e.g., Alonzo 2011).

We explore two different approaches to modeling student learning: one prominent in the United States (US) and one prominent in German-speaking countries. In the former, learning progressions (LPs) describe the thinking or performances of practices typical for students as they learn. In the latter, competence models (CMs) "are detailed descriptions of intended student learning outcomes in terms of knowledge, abilities, and skills in specific areas which are derived from teaching methodology and learning psychology" (Zlatkin-Troitschanskaia et al. 2017: 23). LPs and CMs both articulate qualitatively different levels of a given competence, yet these

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two models of student learning differ according to a number of criteria. In this chapter, we highlight similarities and differences with respect to four of these: kinds of models, model structure, application to teaching and learning, and evaluation through research. In order to illustrate our comparison, we use examples of one LP (Schwarz et al. 2012) and one CM (Krell et al. 2016; Upmeier zu Belzen and Krüger 2010) for models and modeling in science education. By doing so, we aim to gain a deeper understanding of both approaches and, thus, to inform efforts to understand and support teaching and learning in science.

Learning Progressions and Competence Models

Both LPs and CMs arose from concerns about student achievement prompted, at least in part, by international comparisons such as PISA (OECD 2000) and TIMSS (Martin et al. 2012). LPs were formally introduced (National Research Council 2007), in part, in response to critiques of US science curricula as shallow and incoherent (Schmidt et al. 2005). In Germany, CMs were introduced as part of a paradigm shift, from the acquisition to the application of knowledge, in response to the so-called PISA Shock of the early 2000s (Klieme and Hartig 2008). While the US response focused on learners and the coherence of their educational experiences, the German response focused on learning outcomes in combination with competence-oriented teaching.

The Learning Progression Approach

LPs are "descriptions of the successively more sophisticated ways of thinking about a topic that can follow one another as children learn" (National Research Council 2007: 219). LPs are typically organized into levels, with the lowest level (the lower anchor) describing students' pre-instructional ideas or practices, the highest level (or upper anchor) describing expectations for student outcomes, and intermediate levels describing ideas or practices that are typical as students move from the lower to the upper anchor. LPs have an explicit focus on the way students approach a given topic or practice. Rather than breaking scientific ideas or practices into constituent components through logical analysis, resulting in strand maps that illustrate connections between components or lists of components ordered by difficulty, LP levels describe the ideas or practices characteristic of students with different degrees of sophistication. Differences between levels of an LP are qualitative, reflecting different ways of thinking about a single topic or performing a single practice, rather than the acquisition of additional knowledge and/or skills. LP researchers are careful to note that LPs are not developmentally inevitable, and many argue that an LP must be accompanied by "instructional components" describing the instruction that is necessary to advance students from one level to the next (e.g., Krajcik 2012: 32).

Although not always explicitly included in LPs, researchers also acknowledge that there is likely variation in students' progress from the lower to the upper anchor of an LP (e.g., Corcoran et al. 2009) and that, as models, LPs can only approximate students' cognition and learning (e.g., Alonzo and Elby 2019). One is likely to see deviation from the neat progress represented between the lower and upper anchors of a given LP, i.e., the "messy middle" (Gotwals and Songer 2010: 277).

The Competence Model Approach

Competences are defined as "domain-specific cognitive dispositions that are required to successfully cope with certain situations or tasks, and that are acquired by learning processes" (Koeppen et al. 2008: 68). Essential elements of this definition are the domain specificity and learnability of competences, since the construct was introduced as an alternative to the focus on domain-general cognitive dispositions that are learnable only to a limited extent (e.g., intelligence). Competences reflect a person's potential to meet cognitive demands in specific areas of learning and behavior in order to successfully solve problems in various situations (Klieme et al. 2008). In other words, competences are latent and complex constructs including both knowledge and skills that become manifest during performance. However, following Ropohl et al. (2018), the concept of competence is still under discussion because of its many constituents. Even though definitions of competence include both cognitive and volitional components, the latter are often not included when competence is operationalized in CMs (Koeppen et al. 2008).

CMs are located between the theory of competence and competence-oriented teaching. This means they are a domain-specific operationalization of the theory of competence, developed with regard to elements of teaching and the outcomes of learning. CMs are derived from teaching methodology and psychology of learning. Typically, CMs are two-dimensional frameworks that represent a given competence with a set of sub-competences (one dimension), each with qualitatively different levels (the other dimension). Initially, these frameworks are conceptualized as structural models. Once there is empirical evidence that the levels are ordered hierarchically as postulated, CMs may become developmental models (e.g., Schecker and Parchmann 2006).

Criteria for Comparison of Learning Progressions and Competence Models

There is no single template for either LPs or CMs. Each approach encompasses disagreements about what "counts" as an LP or a CM, and significant variation exists within examples of each approach, such that an absolute comparison, applicable to all LPs and all CMs, is not possible (e.g., Hammer and Sikorski 2015).

Nevertheless, in the sections below, we attempt to generalize across LPs and CMs to describe and compare the two approaches with respect to four criteria: kinds of models, model structure, application to teaching and learning, and evaluation through research.

Kinds of Models

With LPs and CMs as two alternative models of student learning, we start by considering the kind of model each represents. LPs articulate different levels that describe student thinking or practice as it typically develops. Because LPs emphasize the nature of students' thinking or practice, they include both canonical and noncanonical ideas characteristic of students with a given level of sophistication (Corcoran et al. 2009). They focus on the development of students' ideas and practices, and thus LPs can be seen as developmental models (Schecker and Parchmann 2006), based on available evidence of student thinking and learning. In contrast, at least initially, CMs are typically structural models (Schecker and Parchmann 2006), representing a set of sub-competences with qualitatively different levels. CMs contain descriptions of achievement or competence: what students theoretically should know and be able to do. When a CM is first proposed, there is not yet empirical evidence that justifies the relevance and discriminatory power of each sub-competence and the hierarchical ordering of levels (e.g., Schecker and Parchmann 2006). Although LPs typically focus on a single topic or idea and thus may have a narrower scope as compared to CMs, LPs are not always unidimensional. They may include multiple progress variables (Wilson 2009) or dimensions that progress together as students learn.

Model Structure

Both LPs and CMs are organized in terms of levels that are not regarded as developmentally inevitable stages (Krell et al. 2016; Smith et al. 2006); rather, they describe what learners can accomplish with suitable learning opportunities. However, as LPs and CMs represent different approaches to modeling student learning, their respective levels have somewhat different meanings. With their focus on the development of student ideas and practices, LPs represent a contextualized, evidence-based argument about potential pathways learning can take. In other words, LPs explicitly hypothesize an ordering of the levels through which students develop more sophisticated ideas and/or practices. In contrast, levels in a CM are meant to be qualitatively different in an ordinal sense, not necessarily describing hierarchically ordered developmental stages. Thus, learners do not necessarily have to go through the levels in a particular order during the learning process, although such an ordering might be later revealed. Rather, during the learning process, learners can move individually through the levels of each sub-competence of the CM.

Application to Teaching and Learning

A key application of LPs and CMs is to provide support for teachers' classroom instruction. As models of student learning, both mediate among standards, objectives, and teaching and learning activities. Both may help to break down standards into learning goals for units or even lessons. This is particularly important in the German context, in which standards are defined for the end of schooling and, thus, provide distal goals for teaching and learning (von Aufschnaiter and Hofmann 2014). Therefore, CMs provide a link between the standards and the respective educational theory, first by providing a theoretical justification for the standards and second by decomposing the standards into subordinate targets (sub-competences and levels). The levels of a CM can guide the development of domain-specific sub-competences. However, while levels of an LP may be directly used to develop curriculum materials and instruction that support students' progress along the pathways described in the LP, CMs often are not directly suitable for teachers. Therefore, CMs might be operationalized in concrete and detailed rubrics, which define expectations in terms of indicators of observable student performance (Burke 2006; Grünkorn et al. 2014a). Both LPs and CMs can be used to diagnose student achievement in terms of their respective levels, and such diagnoses may be used to identify appropriate instruction to help students advance from one level to another (e.g., Schecker and Parchmann 2006).

Evaluation Through Research

LPs and CMs start out as hypotheses; however, in contrast to CMs, LPs are generally proposed on the basis of empirical evidence of student understanding of a given topic, or performance of a given practice, and how it develops. For both LPs and CMs, evaluation relies on qualitative and quantitative methods. LP evaluation efforts focus on both individual cells (ideas or practices at a given level) and whether the LP as a whole captures student learning. Therefore, longitudinal studies over the span of the LP are preferred, but teaching experiments (demonstrating movement from one level to the next), and even cross-sectional studies, are also used (Corcoran et al. 2009). Often, work to explore students' movement through an LP involves design research, in which the LP is refined along with instruction designed to support student learning with respect to the LP (e.g., Wiser et al. 2012). Ultimately, evaluation of an LP entails not only its content but also its utility, e.g., for informing teachers' practice or the development of effective curriculum materials (e.g., Songer et al. 2009). For CMs, the postulated structure of the model, with sub-competences and levels, might be evaluated qualitatively, e.g., in cognitive labs, or quantitatively, e.g., using test instruments and statistical analyses (Zlatkin-Troitschanskaia et al. 2017). In the latter, the cells of the model are operationalized into tasks, which are solved by learners in cross-sectional or longitudinal studies. The data are used to investigate the postulated structure of the CM, and, with

sufficient evidence, structural models might become developmental models (Schecker and Parchmann 2006).

In the following we apply the criteria presented above to compare an LP (Schwarz et al. 2012) with a CM (Upmeier zu Belzen and Krüger 2010) for models and modeling in science education.

Application to Models and Modeling in Science Education

Models and modeling in science education have been under intensive research for nearly 40 years (Gilbert and Osborne 1980; Grosslight et al. 1991), stressing the importance of thinking with models scientifically and engaging in inquiry through modeling (Gilbert and Justi 2016; Nicolaou and Constantinou 2014; Passmore et al. 2014; Schwarz et al. 2012; Upmeier zu Belzen and Krüger 2010). This goes beyond the conventional use of models in science classes, which often is limited to representing content knowledge for learning science (Hodson 2014). In many science education standards documents (e.g., Germany: KMK 2005; USA: NGSS Lead States 2013), the application of knowledge about models and modeling in processes of scientific inquiry (Krell et al. 2016) adds the perspective of models as research tools to the traditional use of models as media to represent content knowledge (Passmore et al. 2014; Upmeier zu Belzen and Krüger 2010).

For these two possible applications of models as media or research tools, respectively, it is crucial to distinguish between two relations between the model and its target (Mahr 2011; Gouvea and Passmore 2017): "model of something," the retrospective and more or less ontological view of the process of model creation, and "model for something," the prospective view of the application of a model.

Currently, there are multiple approaches that describe practices, skills, (meta-) knowledge, and/or competences concerning models and modeling in science education (e.g., Crawford and Cullin 2005; Krell et al. 2016; Nicolaou and Constantinou 2014; Oh and Oh 2011; Passmore et al. 2014). All of these approaches propose relevant aspects of learning and teaching science with and about models and modeling, some with reference to model-based learning (Clement and Rea-Ramirez 2008) and model-based teaching (Gilbert and Justi 2016). In these approaches, there is rough consensus about which knowledge and skills should be developed in science education (e.g., Gilbert and Justi 2016): knowledge about models (ontological and epistemological nature of models, why they are constructed and used, assessment of their scientific value), knowledge about modeling (ontological and epistemological grounds for model construction, procedures in model construction, and evaluation of these procedures), and skills in the practice of modeling (constructing models consistent with prior evidence and theories; using models to illustrate, explain, and predict phenomena; comparing and evaluating the reflective potential of alternative models; and revising models to increase their explanatory and predictive power). Many of these approaches served as a

basis for the development of the LP (Schwarz et al. 2012) and the CM (Upmeier zu Belzen and Krüger 2010).

Description of the Learning Progression for Models and Modeling

The LP proposed by Schwarz et al. (2012) was designed to characterize students' knowledge and practice when engaged in modeling, rather than to evaluate students' conceptions about models. It has two dimensions: a generative dimension (models as tools for predicting and explaining) and a dynamic dimension (models as changeable entities). Originally, both dimensions were structured into four levels of reflective practice that capture growth in students' understanding and performance (Schwarz et al. 2009). These levels refer to four elements of practice: constructing, using, evaluating, and revising models to enhance their explanatory and predictive power. For two of the levels, further empirical investigations led to the separation of the generative dimension into four subdimensions: attention to abstraction and representation of the features of the model, clarity of communication and audience understanding, support using evidence, and mechanistic and process-oriented explanation versus illustrative/descriptive accounts. Each of these subdimensions has three levels (Bamberger and Davis 2013; Schwarz et al. 2009). Bamberger and Davis (2013) considered an additional dimension: comparativeness (how models differing by time or condition help to understand the scientific phenomenon). This dimension was used along with three subdimensions of the generative dimension (representation, communication, and explanation) in order to examine students' ability to transfer modeling performances across content areas. Thus, empirical investigation of the models and modeling LP in teaching experiments and studies of students' performances is an ongoing process leading to changes in the description of dimensions and levels (Bamberger and Davis 2013; Schwarz et al. 2012).

Description of the Competence Model for Models and Modeling

Following Weinert (2001), Upmeier zu Belzen and Krüger (2010) defined model competence as the ability to gain purposeful new insights while modeling, the ability to judge models and the modeling process in relation to the purpose, the ability to reflect upon modeling processes, and the motivational and social willingness to use these abilities in problem-based situations. The CM for models and modeling in science education is based on a review of relevant literature on models and modeling (c.f. Krüger et al. 2018). The literature provides descriptions for sub-competences and levels of understanding. For instance, Crawford and Cullin (2005) developed a matrix

with five dimensions (sub-competences) describing four levels: limited, prescientific, emerging scientific, and scientific. All literature about models and modeling reviewed by Upmeier zu Belzen and Krüger (2010) only implicitly integrates the aforementioned distinction between models of something and models for something.

The resulting CM contains five sub-competences: purpose of models, testing models, changing models, nature of models, and multiple models. The CM distinguishes three levels of understanding for each sub-competence (Krell et al. 2016; Krüger et al. 2018). These levels characterize increasing complexity when thinking about a model (level 1, limited view of the representation of the model; level 2, understanding of model creation, model of something; level 3, perceiving a model as a scientific idea and a research tool, model for something). The structure is restricted to cognitive aspects that are needed to solve domain-specific problems (Koeppen et al. 2008).

Comparison Between LP and CM for Models and Modeling

Kinds of Models

As described above, LPs are developmental and CMs, at least initially, structural (Schecker and Parchmann 2006). The kind of model has to do with the respective purposes of LPs and CMs, which affect how the LP and CM for models and modeling were created. The models and modeling LP describes pathways for student learning and, therefore, was based on prior research, theoretical arguments, and empirical observations of science lessons (Schwarz et al. 2012), with a focus on what is most productive for learners. Empirical investigations in classrooms were used to design appropriate descriptions of dimensions and levels of students' individual development while learning about models and modeling (Schwarz et al. 2012). The resulting LP represents a developmental model, in that it describes paths through which students can engage with more sophisticated modeling practices over time.

The CM was based on theoretical work (e.g., Mahr 2011) and empirical evidence (e.g., Crawford and Cullin 2005) from already existing research about models and modeling. Thus, the CM initially was a hypothetical structural model (Schecker and Parchmann 2006). After many years of research on the postulated structure, the sub-competences have been shown to be statistically separable (Krell 2013). Students' responses to a set of contextualized items revealed that the cells of the CM provide valid descriptions of the postulated structure (Grünkorn et al. 2014b). Frequencies of student answers from cross-sectional studies showed that the levels are ordered from low to high difficulty (Krell 2013; Terzer 2013).

Model Structure

Consistent with the comparison above, (a) the LP and CM for models and modeling are organized into levels that require suitable learning opportunities for students to achieve, and (b) while the LP describes the pathway that students might take through its levels, the CM does not. However, in both approaches, research is used to investigate the way that students do progress through the levels. For the LP, this has occurred through experimental interventions (e.g., Schwarz et al. 2012) as part of the aforementioned design work. For the CM, this has occurred through longitudinal studies with test instruments (Patzke et al. 2013). While the levels initially were not posited hierarchically (i.e., learners do not necessarily have to go through the levels in a particular order during the learning process), longitudinal studies might show a hierarchical order. However, evidence available so far only supports the CM as a structural model: data has provided evidence that the descriptions of the sub-competences and levels are accurate (Grünkorn et al. 2014b; Krell 2013; Terzer 2013).

Application to Teaching and Learning

For the models and modeling LP, application to teaching and learning was a component of the iterative process involving theoretical and empirical work during the development of the LP. This process of designing and revising the LP was constrained by what is possible in classrooms with existing curriculum materials and teachers. Therefore, a parallel process of designing effective curriculum materials (Schwarz et al. 2009) and professional development materials to support students and teachers in their enactments of the practice was undertaken as part of the design work to develop the LP. Characterizing and comparing possible paths for learning a particular target concept evolved from design considerations. When applying the LP to teaching and learning, Schwarz et al. (2009) also needed to consider how to balance metaknowledge and practice, how the practice was enacted across science topics, and the appropriate grain size for capturing student learning and for highlighting particular forms of models and elements of modeling practice.

As the CM was not developed through empirical approaches via classroom enactments, the CM was applied to teaching and learning only after a long search for evidence concerning the appropriateness of the structure (Krell et al. 2016). At this point, the dimensions and levels were implemented as national reference frameworks from the government (e.g., Berliner Rahmenlehrplan 2014) and in teaching materials from publishing companies (e.g., Fleige et al. 2012).

Evaluation Through Research

As for other LP research, in work on the models and modeling LP, both descriptions of the levels and the student development that they describe were explored through ongoing design research used to evaluate and refine the LP. Researchers needed to explore which aspects of scientific modeling practice are both feasible and productive for learners, as well as challenges and successes in reaching particular learning goals, in order to develop design arguments for the learning goals expressed in the LP (Schwarz et al. 2012). These design arguments became part of the postulated levels of the models and modeling LP. In addition, investigating the LP required effective assessments of modeling practice, as enacted across multiple science topics, and appropriate analytical tools for interpreting outcomes.

As is common for CM research, evaluation of the CM for models and modeling has, thus far, focused on its structure through both cross-sectional and longitudinal studies. Several studies have provided empirical evidence confirming the structure (sub-competences and levels) of the CM (e.g., Grünkorn et al. 2014b; Krell 2013; Terzer 2013). Further attempts to evaluate the CM as a developmental model are being conducted in intervention studies with in- and pre-service teachers (Günther, et al. 2019; Mathesius et al. 2016). Ultimately, these results might offer evidence for the appropriateness of the CM as a pathway for student learning.

Thus, empirical research on LPs and on CMs for models and modeling differ fundamentally in their approaches. The models and modeling LP has been developed based on design-based research used to iteratively develop the LP along with instruction that can help learners meaningfully engage in modeling practices. Work on the CM, in contrast, has taken place outside of an instructional context. The structure of sub-competences and levels was evaluated using assessment tools with populations with postulated differences in models and modeling competence.

Discussion and Conclusions

Both the LP approach and the CM approach are still ill-defined (Hammer and Sikorski 2015; Ropohl et al. 2018). As Sikorski and Hammer (2010: 1032) stated for LPs: "Given the speed of its adoption, it is not surprising there are variations in how the notion is understood, regarding how to assess sophistication as well as how to conceptualize progress." However, despite great variation within each approach, we see important similarities and differences.

Both LPs and CMs describe latent constructs that are evaluated using assessments. Both are structured in terms of levels, describing sophistication with respect to one or more dimension(s) of student achievement and/or performance. Both are investigated through empirical studies and have as an aim support for teaching and learning.

However, even in this brief overview of some key criteria presented here, we see important differences between LPs and CMs. LPs' focus on student learning

means that they tend to focus on a narrower "slice" of the curriculum, providing more detailed information about how students' ideas develop. In contrast, the focus on learning outcomes in CMs, coupled with end-of-schooling standards, means that CMs take a much broader perspective, often providing a more connected view of the different knowledge and practices being developed with help of several CMs in a domain.

LPs aim for fidelity to the nature of student thinking, whereas CMs are concerned more with alignment to standards (i.e., student achievement). As such, levels of LPs include both canonical and noncanonical characteristics, whereas CMs include only canonical aspects of competences. LPs with their developmental focus help to foreground students' thinking about specific concepts, whereas CMs' broader scope and structural focus might provide a foundation for describing the larger landscape of student learning in science.

Although both approaches are valued for their contributions to teaching and learning, differences in their origins and original purposes have led to different emphases in the research efforts associated with LPs and CMs. LPs are grounded in empirical evidence of student thinking and learning, and their evaluation may also be considered with respect to utility (e.g., Songer et al. 2009). For example, the iterative development of the models and modeling LP using evidence of students' engagement in modeling practices when experiencing simultaneously-developed curriculum materials results in a strong hypothesis about how to foster students' modeling competence (Bamberger and Davis 2013; Schwarz et al. 2009, 2012). In contrast, CMs are theoretically grounded, and associated evaluation efforts focus on the empirical demonstration that the cells of the model (i.e., sub-competences with levels) describe separable parts of the competence (Zlatkin-Troitschanskaia et al. 2017). CMs are often transferred into operationalized indicators (i.e., rubrics; Burke 2006) for competence-oriented classroom applications (Reusser 2014). For example, work on the CM for models and modeling has proceeded from evaluation of its structure (Krell et al. 2016) to development and use of instruments to assess competences, e.g., in large-scale longitudinal studies (Mathesius et al. 2016), to diagnosis of student learning (Gogolin and Krüger 2017) and finally to the use of the CM as an empirically-grounded, theoretical basis for the development of curriculum materials (Fleige et al. 2012).

Appreciating differences between the two approaches (as illustrated through our comparison of the LP and CM for models and modeling) can foster communication between researchers, such that insights from both traditions might be combined to enrich research and practice. LPs show us how to foreground student thinking and/ or practices and student learning. CMs provide a strong foundation for empirically testing the structure of a competence, which can support understanding of the sub-components and levels of the competence and perhaps student learning.

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Science Teaching Through the Lenses of Students: Lower Secondary School

Eva Pennegård

Introduction

While various researchers have argued that teacher quality is one of the most important influences on student learning (Hattie 2009; Nilsson and Loughran 2012), there is limited consensus about what that teacher knowledge looks like in action. As a way of making different components of teacher knowledge explicit to teacher educators, Shulman (1986, 1987) introduced the concept of pedagogical content knowledge (PCK). Since then, researchers have investigated and developed the concept of PCK as a possible way to describe the professional knowledge of teaching to better meet students' learning needs. Loughran et al. (2004) proposed a reflective tool called content representation (CoRe) in order to unpack the embedded components in PCK. With the help of explicit prompts to reflect on when planning, teachers can use CoRe to reveal the tacit parts of PCK (Loughran et al. 2004; Nilsson and Loughran 2012). Eames et al. (2011) found that the tool helped both novice and experienced teachers to develop their PCK while working together. The teachers became more sensitive to students' needs (Eames et al. 2011).

Cross and Lepareur (2015) investigated the connection between PCK and students' growing understanding in physics and highlighted that there is not a linear connection between PCK and student learning, but rather that PCK must be understood in relation to the complicated and multifaceted context in which teaching is conducted. Teaching and learning is best seen as a communicative process in which the concept of didactic contract could be a way to improve understanding of the complexity of teaching and learning. Cross and Lepareur (2015) argued for the need to understand more about how the concept could be taken into account in the PCK model.

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One model that is suitable for explaining the connections between student outcome and teachers' PCK in action is the model of consensus (Fig. 1, Gess-Newsome 2015). This model offers explanatory power for researchers and a way to understand the complexity of teaching. It is a model of teacher professional knowledge and skill, including PCK, and influences classroom practice and student outcome.

The model takes student outcome into account as a facilitator for teacher learning. Teacher affect is recognized as a component of amplifiers and filters. The model describes teacher professional knowledge and skill (TPK & S) and illustrates schematically how the theoretical knowledge is translated into practice (Fig. 1). The model includes something described as amplifiers and filters. Both teachers and students are transmitters and recipients in a context where expectations, preconceived opinions, self-esteem, and prerequisites act as filters and amplifiers. This, in turn, affects how teachers' professional knowledge is shaped in action and how it will be perceived by students in the current classroom practice. It also affects how the teacher's professional knowledge will develop. In the model, PCK is described both as knowledge used in the planning and implementation of subject-specific teaching and as a skill or ability used while teaching takes place. The consensus model introduces a perspective that includes both a theoretical and experience-based knowledge in PCK and the ability to translate this knowledge into practice. The model provides the possibility to investigate PCK in a classroom context while teaching. The student's perspective is included in the model as both the student's results and classroom events, which can give the teacher new signals or new knowledge that affects both the teacher's topic-specific area and the professional knowledge and skill (Gess-Newsome 2015). It was announced during the ESERA-2017 Conference that the model is undergoing further development. Papers from the conference describe how the world's PCK researchers continue to emphasize the need to further pay attention to the students' knowledge development and to link this to research on teachers' PCK (Berry et al. 2017).

From a sociocultural perspective, teachers' professional development also lies in the learning process. Vygotsky and Cole (1978) used the Russian term *Obuchenie* to explain that the teaching process has a dialectic relationship between teaching and learning. To be able to teach, you must know about how the student learns. To be able to learn, you have to teach the meaning and communicate what you learned to the teacher.

The present study seeks to examine how teachers' PCK is expressed in a science teaching practice, from both teacher and student perspectives. As such, the aim is to make the action parts of PCK more visible for teachers and students. The study aims to investigate the fields in which teachers' understanding of how students understand the teaching can be important and, in so doing, contribute to the area of professional development. The research questions for the study are the following: How do teachers describe and reflect their PCK in action while teaching physics and how do teachers reflect when reading students thoughts about which of the teachers' actions students find facilitate their learning? This chapter focuses on the second question, regarding how teachers respond to students' reflections about actions of teaching.
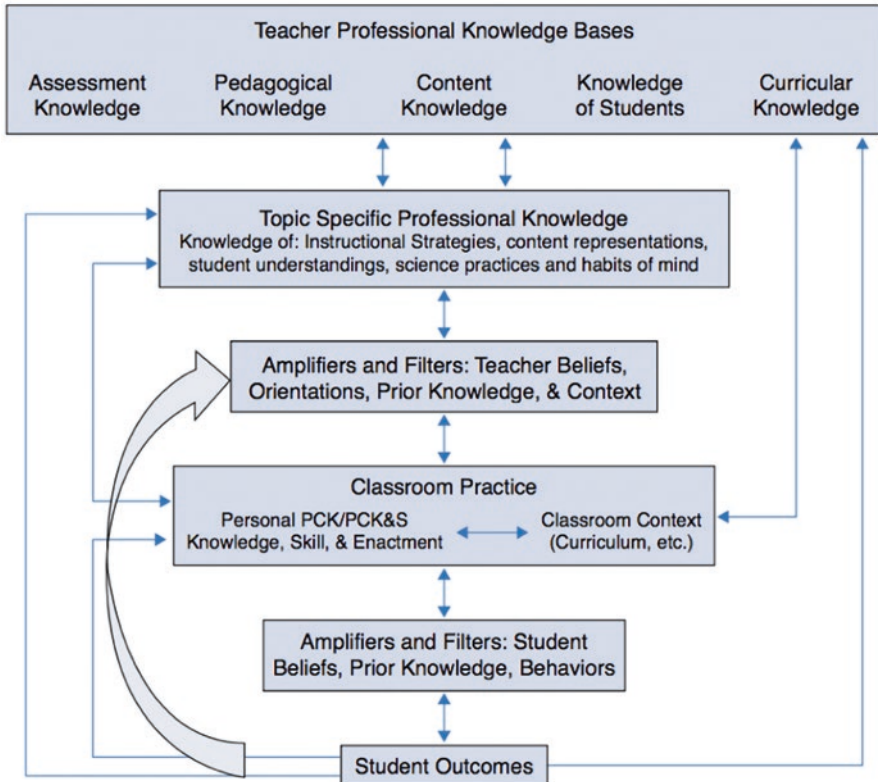
Fig. 1 Model of consensus (Gess-Newsome 2015). The model visualizes teacher professional knowledge and skill, including PCK and its influences on classroom practice and student outcomes. This model was used as a tool for analysis of the data in the study

Method

This is a qualitative case study of three teachers' physics lessons in grades 7–8 in a lower secondary school in Sweden (Cohen et al. 2011). The teachers were all experienced and served as head teachers at their schools. The teachers were informed about the study, the design (Fig. 2), and the extent of their participation, and they all participated voluntarily. The parents of the students gave written consent for their child to participate in the study. The study included several analytical units in its design. These units included sound recordings, video-recorded classroom observations, teachers' protocols (CoRe), as well as students' results, interviews, and reflected conversations stimulated from video films in video clubs (Johnson and Cotterman 2015; Sherin and Han 2004; Sherin and van Es 2009; van Es 2014; van Es and Sherin 2010). Since the transcribed conversations from the video clubs were the primary sources of data, the video club research method is described further below.
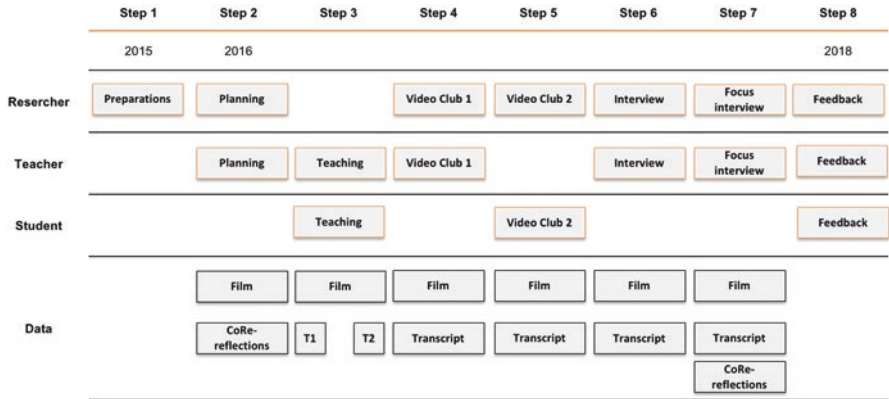
Fig. 2 Illustration of the research design. The horizontal rows describe the logistics of the study, and the vertical columns show the different steps the activities, who attended in them, and what data it generated

Research Design

The design and logistics of the study are visualized in Fig. 2 and are referred to in the text as the research design of the study.

Video Club

The concept of video club was previously used in educational research studies (Nilsson and Elm 2017; Johnson and Cotterman 2015; Sherin and Han 2004; Sherin and van Es 2009; van Es 2014; van Es and Sherin 2010). In a video club, filmed sequences from the environment, in this case three lessons in physics, are used as a basis for group reflection. The participants investigate the subject matter. Video club as a method has been described mainly as a way for teachers to develop professionally. During lessons, the teacher is often highly motivated to act and interact with students, while teachers in a video club are more able to reflect and describe what happened during the lesson. In a video club, teachers have the opportunity to give words to some tacit knowledge (Sherin and Han 2004). In the present study, both teachers and students attended the video clubs (Fig. 2). The focus was on how teacher actions in the classroom facilitate students' learning.

Video club is suitable for qualitative case studies, such as the present study, where the object of interest is what a teacher does in a classroom and how students and teachers reflect on this. However, the method needs to be supplemented with additional data, such as interviews or observation notes that can contribute to a deeper understanding of the data (Jensen and Winitzky 2002). An opportunity for triangulation of data increases the possibility that interpretations become more

trustworthy; hence more sources provide greater opportunity to highlight the investigated phenomena from several angles (Bryman and Nilsson 2002).

The teachers reflected on their PCK collaboratively, with the help of the conceptual tool CoRe before teaching (step 2, Fig. 2). They taught three different aspects of physics – the energy principle, magnetism, and support surfaces – in three different classes. The lessons were video-recorded with two cameras in the classroom (step 3). The teachers and the researcher met three times in the video club to watch three video-recorded lessons (step 4). Students in each class were asked to join the researcher in similar video clubs to watch and talk about the lesson they had participated in. Six to eight students in each class were willing to contribute in the video clubs (step 5). The films were used in a video-stimulated recall interview (video club) where the participants stopped the film when they found some important teacher action they wanted to discuss, pinpoint, or criticize. The video clubs were filmed and later transcribed using Transana, a tool for transcription and analysis (Thorsteinsson and Page 2009). Before the next step, the students' transcriptions were presented to the teachers. After their reading, the teachers were interviewed (step 6) in a semi-structured way (Cohen et al. 2011). The final step in the data collection was a focus group interview (step 7) with the three teachers together (Cohen et al. 2011). All interviews were transcribed, and the transcriptions from the video clubs and interviews were the primary data for this study. As such, the data were analyzed to find how teachers identify and reflect on their PCK in action. The data also shows how the students find the teaching to facilitate their learning and how teachers reflect on information from students regarding their views on the teachers' teaching. This chapter only presents parts of the study; the focus is on how teachers reflect on their actions in a classroom based on the data from students' reflections in video club 2. Data from steps 5–8 were used to answer the following question: How do teachers reflect their teaching when listening to the students' opinions about which teacher actions in classroom facilitate their learning?

Analysis

The study's process of analysis (step 8) had a hermeneutical and iterative approach where the data were analyzed with a qualitative content analysis method (Gadamer et al. 2004). In the hermeneutical tradition, interpretation is used as the main research method. The analysis was conducted in three phases, with the first phase using data from video club 1, the second phase using data from video club 2, and the third phase using data from the teacher interviews. The three phases of analysis enabled the triangulation of data from various sources. Gess-Newsome's (2015) "Consensus model of PCK" (Fig. 1) was used both as a methodological and a theoretical framework in order to reflect the teachers' perception and interpretations of how to transform PCK into action. The second research question is about how teachers reflect on their students' perceptions of the teacher's actions in teaching. It is the second question that the present chapter focuses on.

Results

How do teachers reflect on their teaching when listening to students' opinions about which teacher actions in classroom facilitate their learning? Two key themes in the results highlight important aspects:

- The importance of reflection for professional development
- The importance of developing knowledge about students' knowledge and understanding

The Importance of Reflection for Professional Development

Teachers take advantage of hearing students reflect on teaching and also benefit from participating in a video club with colleagues. They say that these conversations with colleagues contribute to their own development by giving them the opportunity to stop and reflect on the teaching that has been completed. They consider both the conversations with colleagues and getting to know students' reflections on teaching as meaningful. Teachers express that these affect them in ways that probably lead to professional development:

> I think this gives me a lot; not only what the students say, but also our meetings in video clubs, where we could stop and reflect for a moment. You talk a lot about the importance of developing your content knowledge, but I don't think that is where I need to develop; instead, I need to be more responsive to the students. (Quote from teacher 3)

Teachers highlight that differences between teachers and students' reflections are interesting. Students' reflections contribute to a new perspective for teachers. Teachers notice that, in their collegial conversations, they talk about didactic aspects that they actually already know are good. They are looking for actions that they know, according to the research, facilitate student learning:

> In some way, we slip into things that we already know are good. Do you see what I mean? We know it's good to reinforce, we know it's good with concepts. (Quote from teacher 2)

In their reflections, teachers express the benefit of the students' slightly different perspective on the teacher's actions. Unlike teachers, the students are not affected by educational literature and, according to the teachers, seem to be more based on their own individual perspective. To some extent, teachers are surprised that the students think so much about what the teacher does:

> ... they see a lot more from their own perspective. I look more at goal achievement from a class perspective. It's really interesting with students who, in a serious way, have reviewed a lesson. (Quote from teacher 2)

The fact that colleagues are talking to each other in video clubs partly helps teachers leave their own perspective by taking part in a critical and developed reasoning from colleagues. On the other hand, the teachers discuss that there are limita-

tions in conversations between colleagues because colleagues have, to some extent, the same understanding of what, according to current research, are constructive ways of teaching in the teacher's professional context. The students' reflections enable other and new perspectives. Teachers expressed amazement and interest in the students' knowledge about teacher's actions. The students' metacognitive ability is highlighted in the result in this theme of the study:

> They think about teaching, they are meta-reflecting about teaching. Not topic-specific content, but how the teacher does and doesn't. They think about why and why not. (Quote from teacher 3)

When students' voices become visible, like in this study, by the teachers reading the students' thoughts about teacher's actions in classroom, it gives the teacher new views on aspects other than those they are looking for. These perspectives help teachers to leave their own ideas of how good teaching is expressed and to see their professional practice from the student's perspective. The students' examination of the teaching adds something that the teachers are interested in and that will help teachers incorporate new knowledge into future teaching. The results show that the students' perspectives can help create a new understanding of how teachers' actions contribute to students' learning in science. The results raise awareness about aspects that the teachers have not noticed before, to such an extent that students know more about the teachers' actions and what lies behind them.

The Importance of Developing Knowledge About Students' Knowledge and Understanding

As stated in the theme above, teachers experience the meaning of listening to students' descriptions about teachers' actions in teaching. The results show that teachers see students in a new way, to some extent. It seems like they had not previously noted that students have similar knowledge of teaching as their own colleagues. Once they did notice, however, they expressed thoughts about the possibility that students' comments could be used to develop teaching:

> I have also thought about interviewing students and that it is a source of excitement if you want to develop professionally. (Quote from teacher 1)

The results show that teachers see new opportunities for professional development by involving students in the teaching itself. The teachers have not previously thought that students have so much to say about the teacher's teaching. This could indicate that teachers have mostly focused on teaching from a teacher's perspective and that they in collegial conversations get the opportunity to reflect on how teaching affects students' learning. Through various forms of assessment, teachers examine how students understand and what they have learned and adjust their teaching based on both formative and summative assessments of students' understanding. The results illustrate that the teachers, by listening to the students' comments on

actions of teaching, get ideas that they could involve students in new ways, for example, by interviewing them about the actions in the teaching. Through students' reflections on teaching, teachers can use students like experts in teaching. Teachers believe that they may be more interested in asking students about the teaching to supplement their own knowledge of students' learning. The results show that students' reflections on teaching could lead teachers to view another perspective that concerns the teacher's actions but from the perspective of the students. Since teachers benefit from learning about how students learn, this information from students will further contribute to teachers' didactic skills. When teachers find out how students reflect on the teacher's actions, there is reason to believe that teachers accommodate an additional dimension of feedback that can develop their teaching.

The results also suggest that the view of teachers' actions differs between students. Some of the teachers noticed that students have different ways of expressing themselves; some have a lot to say and some students less.

Teachers reflected on questions about whether students' awareness of the teacher's actions may be related to how well the students utilize the teaching in science. The teachers problematized students' different understanding of science teaching and reflected on how that would affect students' learning:

> I think it´s about metacognitive ability. It is far from all students who think in those ways. The teacher is the teacher and students don´t question the teaching, if it is right or wrong or appropriate or not. This category of students is more likely to put the blame on themselves when they fail in class, while those who are metacognitively aware certainly can question some actions from us teachers. (Quote from teacher 3)

The results show that, to some extent, the teachers mean that they can get a view of pupils' metacognitive ability by learning about pupils' reflections about teaching. They mean that students' thoughts about themselves as students and whether they can assimilate the teaching should reasonably be linked to their ability to reflect on the teaching. On the other hand, the teachers' description can also be interpreted as meaning that students with a good ability to describe the teacher's actions may question their learning opportunities if they do not believe that the teacher's actions favor them. According to teachers, this category of student would be more likely to place the responsibility outside themselves. This could have a negative effect if communication with the teacher is not constructive and, in such a case, could lead to a changed action that is more likely to facilitate the student's learning. The teachers believe that there is positive link between the student's awareness of the teacher's action and a beneficial learning for the student. The results also show that teachers believe that there may be a negative link between students with less awareness of the teacher's actions and their learning and a risk of blaming themselves for the lack of learning. Students who put the entire blame on themselves risk consolidating an image of themselves as negative, and instead of considering whether teaching benefits them, they think it is their own fault that they do not learn. When teachers gain access to different students' reflections, they receive important information about how students respond to the teaching and, thus, new knowledge from the source that students can offer. This knowledge from students can be translated into the teachers'

teaching practice. In conversation with students about the teacher's teaching, teachers and students come closer to one another.

Discussion and Conclusions

Developing professional knowledge of teaching is a complex process. As Loughran et al. (2004) indicated, teachers need systematic tools to better capture and analyze their own teaching practice. As the present study has indicated, using students' eyes and letting them reflect on their teachers' actions provide a deeper insight into the dialectic relation between a teachers' teaching and the students' learning that Vygotsky and Cole (1978) felt was essential to teaching quality. This result could be an acknowledgement of what Cross and Lepareur (2015) described as a need to make teaching more visible to students and pinpoint the importance of explicit methods for teachers to do that. The result implies that the design of the study could be a way to facilitate what Cross and Lepareur (2015) called for, namely, understanding PCK in action within the complex context where it is conducted.

One conclusion in the study is that teachers who are given the opportunity to reflect on which teaching actions benefit students' learning believe that they get a deeper view of and understanding of students. As in other studies (Eames et al. 2011), teachers became more sensitive to student needs. Conversations between colleagues, on the other hand, tend to get stuck in known patterns, where conversations about different students and how they respond to the teaching receive a lot of focus. Using filmed lessons and strict questions about teacher actions helps teachers focus on their own actions in classroom and reflect about how the actions benefit or do not benefit different students (Sherin and Han 2004).

A further step in the design of this study is where students study lessons in the same way as teachers and where teachers get to know students' thoughts about the teacher's teaching. The teacher receives feedback from students on his or her teaching, which has probably not been received before. Student feedback helps the teacher view their teaching from a new perspective, and it also enables teachers to see the student in a slightly different way. Like Hattie (2009); Nilsson and Loughran (2012) mentioned, there is little consensus about what teacher knowledge looks like in action. It is most likely that students can help visualize that knowledge by putting the teachers' expressed PCK into words. Worth noting is the power a teacher has relative to the students regarding issues such as grade assessment and the possible concerns students can have to express themselves. The students are, in a way, in a state of dependence toward the teacher. This point needs to be considered and weighed into the benefit of the method.

The teachers noticed different levels of awareness from different students, and from that point of view, they reflect on how this knowledge helps them to do more specific prompts in a classroom. It corresponds to the need to understand how students learn, which could be a way for teachers to better teach a variety of students. Similarly, it gives students the opportunity to reflect on teachers' prompts, which

could be a facilitator for their own learning. This may help students' metacognitive awareness to grow, when they are stimulated to put teachers' actions as facilitators for learning into words. In a way, this could meet the need that Cross and Lepareur (2015) formulated as a need for teachers and students to make the didactical contract visible. This point of students' metacognitive awareness would be of great interest for future studies.

This study has not pinpointed any special teacher action as the best action to facilitate student learning in science, as there seems to be weak consensus from students on that point. However, there is some agreement that the way this study is conducted seems to be a way to unpack and understand how the teachers' PCK is expressed in action in a classroom and how it is understood by students. In this case, both students and teachers agree that reflection in video clubs is a way to better understand teaching and learning and the way teaching affects both students' learning in science and teachers' learning about science teaching.

Summary of Conclusions

- The design of the study could be a way to connect PCK to practice.
- Video-recorded lessons help teachers see themselves from a student perspective.
- The design of the study can be a model for school development in practice.
- Teachers believe that they benefit from hearing pupils' reflections on their teaching.
- Students' metacognitive ability can be extended with the help of video clubs.

ESERA Conference 2017

The questions and discussion that arose after my presentation at the ESERA 2017 conference focused on how to understand teachers' reflections and the potential difficulty in interpreting them in a correct way due to different background, orientation, and prior knowledge. This problem is acknowledged in the current study. The argument stresses why it is not possible to provide evidence, in this study, about which teacher action(s) are recognized as the better ones. Rather, the contribution of this study is the process of learning about how students can understand teacher actions. Also of great interest to the audience was the way that students' minds were involved in the study. It seemed like there was agreement about the problem that students are often left "outside" even if they are the subject of teaching. In that way, students can be very important for making teaching understandable to teachers. Students are often neglected when teaching is discussed or developed, but they were involved to the highest extent in the present study. The working method provides opportunities to involve students in a meaningful way.

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Change in First Graders' Science-Related Competence Beliefs During Digitally Intensive Science Workshops

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Introduction

The aim of this research was to examine if a set of three science and technology (S&T) workshops would promote first-grade pupils' science-related competence beliefs. Research in the field of science education has shown that a decline occurs in students' science-related attitudes as they proceed in their school path. For example, according to her extensive review of relevant literature, Christidou (2011) argues that as they advance from primary to secondary education, students rapidly lose interest in science, and they do not see science-related careers as very attractive (Tytler 2014). Tytler (2014) also summarises according to his review of the literature about science attitudes that by the age of 14, for the majority of students, the interest in pursuing further science studies has largely been formed. This fact highlights the importance of focusing on early science experiences. The Programme for International Student Assessment (PISA) framework emphasises attitudes as a key

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component of an individual's science competence. Science competence includes, for example, interest, enjoyment and values related to science and school science. The percentage of students in Finland who reported that they 'agree' or 'strongly agree' with the statements measuring enjoyment of science learning ('I enjoy acquiring new knowledge in science') decreased on average from 64% to 56% between the PISA 2006 and 2016 measurements (Organisation for Economic Co-operation and Development [OECD] 2007, 2016). Further, the percentage of Finnish students who expect to work in a science-related occupation at age 30 is the lowest among the OECD countries, although the percentage increased slightly from 13% to 17% between the PISA 2006 and 2016 assessments. In general, students' low interest and engagement in science learning and science-related careers have received significant attention from policymakers and researchers (Osborne and Dillon 2008; Zeyer et al. 2013). The European Commission's Horizon 2020 Work Programme (European Commission 2016) emphasises that school science should better represent real scientific practices and cater more effectively to the needs and interests of young people. Moreover, the Finnish national core curriculum emphasises the importance of student engagement in science learning (Finnish National Board of Education [FNBE] 2014).

In defining competence (or ability) beliefs, we follow the expectancy-value theory (EVT) of motivation proposed by Eccles and her colleagues (e.g. Eccles 2005). According to EVT, engagement and motivation towards a certain task depend, on one hand, on an individual's expectation of success and self-related beliefs (ability or competence beliefs) and, on the other hand, on values associated with the particular task (Eccles and Wigfield 2002; Pintrich 2003). Expectancies and values are assumed to directly influence performance, persistence and task choice (Eccles and Wigfield 2002).

Task characteristics that are assumed to influence choices can be positive or negative (Eccles and Wigfield 2002), and task-related values can be seen as positive valences of a task (Chow et al. 2012). According to EVT, task-related values can be further distinguished as attainment value, intrinsic value and utility value. The first, attainment value, refers to experienced importance or significance of a topic. It refers to the perceived importance that individuals attach to performing well in, or being competent at, a task (Chow et al. 2012: 1612). The second, intrinsic value, is defined as the expected enjoyment of engaging in a specific activity or task (Chow et al. 2012). If the task holds intrinsic value, the activity itself will be the source of enjoyment, and the outcome of the task will not be perceived as extremely important. Intrinsic value has been found to be related to engagement and persistence in a task (Schunk et al. 2007). The third, utility value, is the perceived usefulness of completing a task for obtaining some instrumental benefit or facilitating the achievement of other immediate or long-term goals (Chow et al. 2012). If the task holds utility value, the activity itself may not be perceived as interesting or enjoyable, but the outcomes of completing the task will be perceived as valuable.

Furthermore, according to EVT, there can be a negative valence related to the task – in other words, the cost of engaging in the task (e.g. Eccles and Wigfield 2002; Gaspard et al. 2015) – because making one choice often eliminates other

options (Eccles and Wigfield 2002). The negative aspects of engaging in a task can be categorised as effort cost, in terms of loss of time; emotional cost, such as stress and anxiety; and social cost, such as becoming an outsider to a peer group. For example, the effort cost relates to the fact that engaging in one task means having to neglect something else and having to make choices between activities. Emotional cost means having to accept a certain amount of anxiety, stress or fear of failure in order to achieve a goal (Schunk et al. 2007). Social cost may mean, for example, time spent away from friends in order to prepare for, and perform well on, a test. If the costs become too high with respect to the expected value of performing well, an individual may abandon the task; conversely, if the task is valued high, the costs will not matter. Despite the costs, if students' attainment and utility values can be influenced and the students can identify personal reasons why an activity relates to their lives, the intervention may promote greater engagement with the topic under study (Harackiewicz et al. 2015).

Besides task-related values, expectancy and personal competence beliefs are central in EVT. Competence beliefs are defined as students' evaluations of their competence in different areas (Eccles et al. 1983). These beliefs are conceived as broad beliefs about competence in a given domain, not one's expectancies of success on a specific upcoming task (Eccles and Wigfield 2002: 119). In the present study, the emphasis was particularly on the students' science-related competence beliefs, although children and adolescents do not usually distinguish between these and expectancies, even though expectancies and competence beliefs are theoretically distinct concepts (e.g. Eccles and Wigfield 1995).

Within the field of science education research, there is a scarcity of studies on science-related competence beliefs among first-grade pupils. However, supporting the pupils' competence beliefs from primary school onwards might promote their science-related motivation throughout their whole school path, because their beliefs about their achievement play a role in directing their behaviour and effort in learning situations (Eccles 2009). However, the development of first graders' motivation has been examined in the context of other school subjects. When examining primary pupils' ability beliefs and performance in Finland, Viljaranta et al. (2016) found evidence that in the context of mathematics and reading, the first-grade children show different motivational patterns or profiles that differ from each other (p. 370). Motivational pattern or profile refers to the idea proposed in person-oriented motivational research that associations between motivational variables are not necessarily similar for all individuals, but they constitute an individual profile. Viljaranta et al. (2016: 371) even argue that when comparing beliefs in one's own abilities and intrinsic, the beliefs might play a bigger role in respect to performance in early school years. In other words, even though the intrinsic value associated with a task is low, the performance can be good if the pupil has high ability beliefs. According to a recent extensive review, Muenks et al. (2018) claim that this relationship between beliefs and performance strengthens across the school years, and even though smaller children seem to be very confident when it comes to their abilities, there is a tendency for competence beliefs to become more negative during the school years. Research related to competence beliefs does not provide a clear view

of whether it is better to have realistic or overly optimistic competence beliefs from the point of view of motivation and performance (Muenks et al. 2018).

In addition, the competence-related beliefs of children become increasingly stable as they age, and this stability makes it difficult to change negative expectancy beliefs as children get older (Muenks et al. 2018). However, the ways in which learning situations are organised and structured with respect to instructional practices strongly influence children's expectancies and competence beliefs (Muenks et al. 2018: 9). When teachers hold high generalised expectations for student achievement and students perceive these expectations, the students achieve more and experience a greater sense of esteem and competence as learners (p. 9). Moreover, interventions have the power to reshape pupils' achievement-related beliefs (Muenks et al. 2018). In the present study, first graders were chosen as the target group for competence-beliefs-promoting S&T workshops. The workshops were designed according to the principles of design-based research (Sandoval 2014; Juuti et al. 2016). The design process is described in detail in the Workshops section.

Research Question

A set of three technology-intensive science workshops was organised to enhance the science and technology-related competence beliefs of first-grade pupils. We assumed that the pupils' science-related competence beliefs may be fostered with offering possibilities to succeed in targeted activities. We also examined if the enhanced feeling of competence was transferable to another context. The research question was as follows: Does the set of three workshops promote science-related competence beliefs?

Context of the Study

This research took place in Finland. The Finnish education system consists of a 9-year comprehensive curriculum, which is then followed by further studies in high school or vocational school. School starts in the year when pupils turn 7 years old; the year prior to this, all children are permitted and recommended to attend preschool. Pupils study in inclusive, heterogeneous groups, and most pupils go to a school near their home. In all groups participating in this research, there were pupils who spoke a language other than Finnish at home. Public schools (majority of the schools) are funded by municipalities, but there are also some private schools in Finland. However, for the pupils, comprehensive school is free of charge whether they go to a private or municipal school.

The national curriculum, which was revised in 2014, defines the minimum level of teaching for each subject for all pupils. The curriculum is subject-based. The

subject science is officially called environmental studies and is taught in grades 1 to 6. It integrates biology, geography, physics, chemistry and health education. In the present study, the workshops were most often related to the physics content. In the curriculum, transversal competencies are also highly emphasised. In the core curriculum, these competencies refer to an entity that encompasses knowledge, skills, attitude, values and will. Competence also means the ability to apply knowledge and skills in a given situation. The manner in which the pupils will use their knowledge and skills is influenced by the values and attitudes they have adopted and their willingness to act. Competence development is influenced not only by the contents on which the pupils work but also by how they work and how their interaction with the environment functions (Finnish National Board of Education 2014).

The transversal competencies introduced in the Finnish national core curriculum are thinking and learning to learn, cultural competence, interaction and self-expression, taking care of oneself and managing daily life, multiliteracy, information and communications technology (ICT) competence, working life competence and entrepreneurship and participation, involvement and building a sustainable future. ICT competence is emphasised in the workshops. In the core curriculum, it is recommended the pupils are supported in familiarising themselves with various ICT applications and that they are guided in using ICT in exploratory and creative work. In this research, pupils use programming and data logging applications in order to reach the aims expressed in the core curriculum. The Finnish national core curriculum introduces multidisciplinary learning modules that integrate the perspectives of different school subjects and enrich the combination with transversal competencies. Multidisciplinary learning modules promote the achievement of goals set for basic education. To ensure that all learners can engage in exploratory work that is of interest to them, each learner must be provided with an opportunity to join a multidisciplinary learning module at least once during each school year. Schools must also provide opportunities for experimentation, exploration, active learning, physical activity and play. Cultural diversity and language awareness are also key principles that guide the development of the school culture (Finnish National Board of Education 2014). The workshops introduced in this article shared features of multidisciplinary learning modules, as they incorporated enquiry skills, programming and science content.

Participants and Procedure

A total of 97 first-grade pupils (pupils' age 7–8 years) participated in this study. Three first-grade classes in one school ((1) N = 20, (2) N = 20, (3) N = 19, 59 altogether) participated in the workshops. The school is located in a suburban area, with relatively high SES. There were 38 pupils in the control group from two other schools in the Helsinki Eastern suburban area.

Substantial research has shown that students' expectancies predict future performance, even when controlling for previous performance (Muenks et al. 2018: 7).

When teachers hold high generalised expectations for students' achievement and students perceive these expectations, the students achieve more, experience a greater sense of esteem and competence as learners and resist engaging in problem behaviours (Muenks et al. 2018: 9). The high expectations of teachers are communicated in the selection of challenging tasks for pupils to perform and through the teachers' belief in the pupils' competence to perform well in these tasks. The teachers communicate this belief in the pupils' capabilities by offering encouragement in spoken form throughout the lesson and especially in situations where the pupils are struggling with some aspect of the task. The workshops were designed according to the Finnish national core curriculum (Finnish National Board of Education 2014), especially the parts such as science content, enquiry skills and transversal competencies. The enquiry skills that first graders should adopt, according to the Finnish national core curriculum, are as follows: Science teaching in the first grade should encourage the pupils to ask questions and use classroom discussions as a starting point for small enquiry tasks. The pupils should be guided to make observations by using their senses and simple equipment and further present the results of their enquiry projects. The pupils should also be guided to act responsibly and to follow instructions. Finally, the pupils should be guided to familiarise themselves with technology and be encouraged to try, invent, build and create in collaboration with others and use ICT as a means of communicating their activities to others. These aims introduced in the Finnish national core curriculum for first-grade science were taken into account, when planning the workshops.

The designing of the teaching sequences followed design principles introduced by Sandoval (2014). He introduces a conjecture-mapping technique in order to 'specify theoretically salient features of a learning environment design and mapping out how they are predicted to work together to produce desired outcomes' (p. 2). In the present study, the elements of the conjecture map were as follows. The high-level conjecture was to engage pupils to perform challenging tasks and, through that procedure, foster their task-related competence beliefs. This conjecture was ensured through scaffolding all the pupils to perform challenging tasks in the workshops. Verbal and concretical scaffoldings were an essential part of the design. The mediated outcome was a result of ensuring that all pupils could carry out the workshop tasks by offering support from teachers. Further, as a learning outcome, pupils' competence beliefs were measured in the competence belief questionnaire administered about a month after the workshops.

Design conjectures take the general form, 'if learners engage in this activity with these tools, through this discursive practice, then this mediating process will emerge' (Sandoval 2014: 7). In the present study, design conjecture was articulated in a form that if pupils engage in digitally intensive science workshops that involve producing electric circuits, programming robots and taking measurements, and if they are scaffolded, the pupils manage to complete the tasks and get support for their competence beliefs.

The embodiment of the design conjectures encompassed tools and materials, task structures, participant structures and discursive practices. The workshops were designed so that the tools and materials were evidently challenging for pupils.

Pupils used electrical components, Lego EV3 robots, computers and Logger Pro computer-based data logging equipment, for example. At the time of the workshops, typically, fifth graders conducted electric circuit investigations or programming practices with Lego EV3 robots. Computer-based data logging was applied occasionally at the middle school level. Many digitally intensive tools that are not used in everyday lessons were used in the workshops. The tools and materials used in the workshops are described in more detail in the section introducing the workshop content and practice.

The general task structure was intended to answer the question, 'What are the pupils expected to do?' In the present study, pupils attending the workshops were expected to perform certain tasks, one at a time. The structure of each task was designed such that pupils would have limited possibilities to compare their performance with that of others. Further, the task was designed so that it would take all pupils about the same amount of time to complete it. In the latter part of the task, there was a possibility of varying the task in order to differentiate the teaching according to the pupils' different needs. There were also several adults in the classroom to support the pupils.

In the first workshop, the pupils worked alone; in the second workshop, they worked in pairs; and in the third one, the pupils worked in a group. The tasks were designed to support the grouping of pupils in that particular situation. In the first workshop, each pupil generated their own piece of art, which they were able to take home with them; therefore, working alone was the most suitable way of working. In the second workshop, the pupils worked in pairs, because the task required negotiation and there were suitable tasks for two people. In the last workshop, four pairs of hands were needed to handle the equipment; therefore, group work was chosen as the instructional method.

The workshops exposed the pupils to discursive practices or 'ways of talking' that aimed at emphasising positive aspects of their performance. During the whole class discussions before introducing the task and after the completion of the tasks, pupils' persistence and performance of the task were praised. Furthermore, the challenge of the task was emphasised. All adults attending the situation (teacher-researcher, teacher, researcher and assistant) gave pupils verbal reassurance that they would manage to complete the challenging tasks. In the scaffolding situations, reasons for the difficulties were attributed to the complex digital tools, not to the pupils' performance. Further, in scaffolding situations, pupils were told that other pupils had faced similar difficulties and had managed well in overcoming them. Further, it was mentioned that this kind problem solving (e.g. 'Solving contiguity disturbance problems in connectors is part of working with digital tools, and now you have experienced how to solve these kind of problems') is typical in S&T-related tasks. Thus, in the workshops, pupils achieved success when performing well in a very challenging task.

Theoretical conjectures in a conjecture map take the following general form: 'if this mediating process occurs it will lead to this outcome' (Sandoval 2014: 7). In our case, the theoretical conjecture could be stated as follows: If pupils manage to perform a challenging and digitally intensive task, their competence beliefs

regarding the task will increase. The challenges of the task and the teachers' beliefs in the students' competence were communicated to the pupils. The data collection methods described in the methods section were intended to examine the realisation of the theoretical conjecture.

In what follows, the workshop activities are described in detail. The activities took place during the spring semester of 2016 and included three 90-minute S&T workshops. The activities in the workshops were planned carefully to follow the Finnish national core curriculum for basic education for primary science (Finnish National Board of Education 2014); therefore, nothing outside the curriculum was included in the workshops. In other words, both experimental and control groups were taught according to the curriculum. In Finland, teachers enjoy broad autonomy with respect to implementing the curriculum and choosing activities and learning materials, and enquiry skills and hands-on experiments are strongly recommended as part of the science subject.

First Workshop The topic of the first workshop was electric circuits. First, pupils individually familiarised themselves with the components of an electric circuit, put the batteries into the battery case and tried to light the bulb. The components were named in a teacher-led discussion. After succeeding in this task, the next task about crafts was introduced. The instruction was to connect the components (batteries and LEDs) with a conductive aluminium tape in such a way that all LEDs would light up at the same time. The pupils were shown a model of the piece of work, which looked like a star shape. Pupils were given as much assistance as they needed. If the LEDs did not light up, pupils were assisted in determining the reason for this. The idea of connecting all the components carefully to build a circuit was emphasised. This task took up the remainder of the lesson.

In the first workshop, batteries, battery cases and bulbs, LEDs, conductive aluminium tape and cardboard were used as tools and materials in order to prepare the artefacts (Fig. 1).

Second Workshop The topic of the second workshop was programming. The pupils first familiarised themselves with Lego programming with Mindstorms EV3 robots and the related software. Since most Finnish children play with Lego even before they go to school, the theme of the lesson was familiar to them. However, programming with Lego EV3 did not involve much Lego building, as the robot vehicles had been assembled in advance. This is because when starting to learn to use the programming software, the components of the robot need to be in their exact places, and there is little room for creativity. Afterwards, when the basics of programming are learnt, different creations can be constructed.

The lesson began by showing the pupils three videos in which there were astonishing and complex constructions built using Lego robots. Then the pupils were given the basic instructions for using the program, how the robot could be switched on and how to download the program. They tried out these tasks together. Then the pupils received a task sheet with the instructions, which they were told to follow carefully. For the rest of the lesson, the pupils practised programming in pairs,

Fig. 1 Pupils' activities during the first workshop

downloaded their programs into the robot and followed how the robot executed the program.

In the second workshop, laptops, Lego EV3 Mindstorms software, EV3 robots (basic model), worksheets for testing the programs and programming challenges were used as tools and materials (Fig. 2).

Third Workshop The topic of the third workshop was related to computer-based data logging. In small groups (three to four pupils per group), the pupils used Vernier LabQuest2 data logging equipment to measure temperature changes, and they drew graphs on paper depicting their data. Certain phenomena were introduced to the pupils (e.g. water boiling, ice melting), and they were asked to record temperature changes within certain time intervals related to those phenomena. Then they constructed a graph based on the data and interpreted each other's graphs.

In the third workshop, Vernier LabQuest portable data logger, temperature probes, beakers and electric kettles were used as tools and materials. Additionally, worksheets for measurements were prepared.

Activities in the Control Group The control group studied according to the Finnish national core curriculum (2014). In Finland the teacher has a high level of autonomy in preparing the yearly plan and planning the teaching sequences. The control group followed the teacher's plans and did not take part in the workshop activities as described above (Fig. 3).

The experimental group answered a questionnaire about their competence beliefs before and after the workshops, in February and in May. The control group participated in ordinary teaching according to curriculum and answered the questionnaire twice, in February and May, as the experimental group. Taking into consideration the pupils' age, the items were highly contextual, focusing on concrete science, technology and craft activities. In the questionnaire, four items focused on the

Fig. 2 Pupils' activities during the second workshop

Fig. 3 Pupils' activities during the third workshop

workshop topics, and two items focused on other topics, and they served as control topics. The post-test took place a month after the workshops. In the questionnaire, the children were asked to evaluate how competent they felt themselves with respect to the topics included in the workshops and topics not included in the workshops (1 = not good at the activity at all, 5 = very good at the activity). The items on this topic were as follows:

Science-Related Skills Practised in the Workshops How well do you think you can:

- Change batteries of a toy?
- Change a light bulb?
- Program a robot?
- Measure water temperature with a thermometer?

Science-Related Skills Outside The Workshops How well do you think you can:

- Use a sewing machine?
- Measure the amount of flour when baking?

There were one or two researchers per class instructing and guiding the data collection. Since not all first graders are very fluent readers by February, the answering proceeded as a guided activity, one item at a time, where the researcher read the item aloud and explained the unfamiliar concepts and showed pictures of the devices, if necessary. The principles of the Likert scale were explained as many times as needed, and the construct of the scale was explained. The data were analysed through a paired samples t-test.

Results

The research question was *Does the set of three workshops promote science-related competence beliefs?* The question was answered by employing a pre-post questionnaire design. In Table 1, the means and standard deviations are presented. According to the paired samples t-test, the workshops increased science-related competence beliefs related to the content of the workshops in the experimental group. However, there was no statistically significant change in the control group (see Table 2).

Discussion

In the present study, we examined first-grade pupils' science and technology-related competence beliefs in digitally intensive workshops. In the workshops, pupils engaged in S&T activities that encompassed electricity crafting tasks, programming

Table 1 Paired samples descriptive statistics

	Experimental group					Control group				
		Pre		Post			Pre		Post	
	N	Mean	SD	Mean	SD	N	Mean	SD	Mean	SD
Science-related topics in the workshops										
How well do you think you can										
Change batteries of a toy?	45	2.58	1.57	3.33	1.64	35	2.89	1.73	3.03	1.58
Change a light bulb?	42	1.60	1.29	2.12	1.55	34	1.59	1.37	1.74	1.48
Program a robot?	39	1.64	1.39	4.26	0.97	30	1.83	1.42	2.43	1.61
Use a thermometer?	43	2.26	1.56	4.09	1.31	32	2.44	1.68	2.69	1.69
Topics outside the workshops										
How well do you think you can										
Use a sewing machine?	41	2.05	1.56	2.41	1.73	34	2.00	1.58	1.71	1.32
Measure flour?	44	3.36	1.78	3.25	1.88	31	2.58	1.75	2.94	1.59

Table 2 Paired samples t-test statistics *(p=0.05)*

	Experimental group			Control group		
	t	df	p	t	df	p
Science-related topics in the workshops						
How well do you think you can						
Change batteries of a toy?	−3.07	44	.004∗∗	−.70	34	.492
Change a light bulb?	−2.05	41	.047∗	−.53	33	.599
Program a robot?	−10.32	38	.000∗∗∗	−1.78	29	.086
Use a thermometer?	−6.38	42	.000∗∗∗	−.83	31	.413
Topics outside the workshops						
How well do you think you can						
Use a sewing machine?	−1.36	40	.183	1.12	33	.270
Measure the amount of flour?	.46	43	.649	−1.38	30	.176

with Lego EV3 devices and computer-based data logging. The workshops, which were planned to follow the national core curriculum for basic education for primary science (Finnish National Board of Education 2014), included activities that were challenging enough but planned in such a way that the pupils could manage to accomplish them. This is in line with Eccles' (2009) argument that success in moderately difficult but achievable tasks (activities that provide both a challenge and the opportunity to achieve mastery) is likely to lead to the greatest increases in expectancy-related self-concepts (p. 85).

Based on the results, we argue that with the set of workshops described in this paper, it is possible to promote first-grade pupils' science and technology-related competence beliefs. There was a statistically significant difference in the items concerned in the workshops. The results are in line with Yeager and Walton's (2011) argument that a correctly timed and planned motivational intervention may be effective in supporting pupils' self-beliefs. According to the extensive review of Muenks

et al. (2018), the competence-related beliefs of children become increasingly stable as they age, and there is a tendency for competence beliefs to become more negative during the school years. Furthermore, Viljaranta et al. (2016) claim that changes occur in the motivational patterns or profiles of children's motivation at the beginning of their schooling, even though some stability can be found in their motivational patterns already in the first grade. The increasing stability of pupils' competence beliefs makes it difficult to change negative expectancy beliefs as they get older (Muenks et al. 2018), and on the other hand, beliefs about achievement direct the pupils' behaviour and effort in learning situations (Eccles 2009). Therefore, it is crucial to try to foster positive competence beliefs in younger pupils through ensuring that the pupils realise they are doing something challenging, that they manage to complete the task and that they are praised about their perseverance and about the completed successful outcome. If there is a tendency for the competence beliefs of pupils to decline, it may be useful to ensure that these beliefs are as high and positive as possible in the early years of schooling, before they start becoming more stable. There was no statistically significant difference in the competence beliefs of the control group between measurements 1 and 2. There was either no statistically significant difference in the competence beliefs of the experimental group in the items that weren't included in the workshops. It can be interpreted that the influence of the workshops cannot be transferred into the context of other topics with first-grade pupils.

As the research data were collected when the pupils were in the first grade, this raises some validity issues, mainly related to the pupils' reading and thinking skills – that is, how well they understood the questions and how well they were able to concentrate when answering them. To diminish the probable biases, the items were read aloud to the pupils, and the researcher made sure that everyone could follow the procedure. With respect to these results, science and technology are understood in a narrow sense as a particular science-related task (e.g. programming a robot). The statistically significant change cannot be tracked outside the workshop topics based on these results. This may be related to young children's way of perceiving the world and their reduced ability to see the big picture and connections between parts. Although the workshops included many kinds of activities and were digitally intensive, it is possible to implement such an approach in ordinary teaching.

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Part IV
Enhancing Science Teacher Education

The Value of School Partnerships in Improving Primary Science Teaching: A Comparison of Two PD Engagement Models

Irina Kudenko, Pauline Hoyle, and Ben Dunn

Introduction and Rationale

There is a growing acceptance that subject-specific professional development (PD) has more impact on teacher practice and pupil outcomes, than generic PD (Cordingley et al. 2015). Yet schools in England, especially primary schools, are inclined to provide their teachers with PD which is delivered internally and/or with partner schools. According to the robust international study (OECD 2014), teachers, who teach single subjects in English secondary schools, engage in less subject-specific PD than their counterparts in most high-performing countries. A 2017 NFER survey of school teachers and leaders (primary and secondary) found that 75% of the surveyed staff in England want more opportunities to participate in subject-specific PD with class teachers rating the value of subject-specific PD higher than generic PD (Cordingley et al. 2018). This contrasts with senior leaders who commonly viewed subject-specific PD as less important partly due to conflicting internal priorities in schools for professional development and limited funding reducing the opportunities for teachers' PD.

Since 2010, there has been a shift in the UK education policy towards a 'school-led self-improving' system (Department for Education 2010; Hargreaves 2010) so that schools and groups of schools have total financial management of schools, including the provision of, and funding for, PD. The policy change has had some positive effects: it has encouraged schools to facilitate teacher collaboration and

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collegial PD internally, increasing school-to-school collaboration and building partnerships with local community and employers. A recent review of school partnerships in the UK (Armstrong 2015) confirmed a proliferation of school-to-school collaboration and a growing diversity of partnership arrangements. Teachers are increasingly expected to work in partnerships in and across schools, making professional learning communities and collegial learning a key form of PD (Lofthouse and Thomas 2015).

However, the shift in policy has resulted in senior leaders prioritising whole-school generic training with less emphasis on subject-specific PD, especially externally sourced expertise to support subject-specific PD (Cordingley et al. 2018). However, the internal expertise and capacity in STEM subject expertise, particularly in primary schools in England, is recognised by the accountability system (Ofsted) as generally low with many teachers lacking the knowledge and confidence to teach in engaging and exciting ways (Wellcome Trust 2014; CBI 2015). In turn, the level of expertise within English primary schools to provide expert subject-specific PD in STEM subjects is also low. It is well established that high-quality and inspirational science teaching in primary schools helps engage young people's interest in furthering STEM-related study and careers (Hattie 2003; Ofsted 2013). Subject-specific PD for primary teachers helps increase their subject and pedagogical knowledge and ultimately improve the quality of science teaching and learning (Murphy et al. 2007). So, it is essential that teachers, particularly primary teachers, have access to subject-specific PD.

School partnerships have the potential to tap into subject expertise in partner organisations and/or collectively source external subject-specific PD. Yet, evidence indicates that like individual schools, many partnerships don't prioritise subject-specific PD. Even when partnerships focus on science-specific PD, they have varying degrees of success in terms of impact and sustainability (Armstrong 2015). It is important to understand how school partnerships can become platforms for effective and impactful subject-specific PD.

The research in this chapter compares subject-specific PD provided by school-led collaborative partnerships with external-led subject-specific PD provided by science education experts. The research uses data from two exemplar programmes which are managed by the National STEM Learning Network (NSLN)[1] in England. NSLN is the largest national provider of a diverse range of subject-specific PD for STEM (science, technology, engineering and maths) educators across all educational phases, including primary schools. Since 2005, the Network has offered STEM educators PD facilitated by expert educational tutors who are usually external to the school. In 2013, responding to the national drive towards school-led self-improvement, the NSLN expanded their model of subject-specific PD to include a programme of support for school partnerships wishing to work together to improve science teaching and learning.

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[1] The authors worked for NSLN at the time of the research. NSLN comprises of the National Science Learning Centre (NSLC) in York and up to 50 Science learning Partnerships (SLPs) throughout England together with partners in Scotland, Wales and Northern Ireland.

Research Questions

This research has compared the effectiveness of two exemplars of subject-specific PD: a school-led collaborative science-specific PD model delivered through the ENTHUSE Partnership Programme (EPP) and externally led PD for science subject leaders delivered through the Primary Science Leadership Programme (PSLP). These two different PD models share a common goal of improving the teaching and learning of science in English primary schools as well as subject-specific leadership to build their capacity for self-improvement. Our research questions are:

In what ways are the two PD engagement models (school-led collaborative subject-specific PD and externally led subject-specific PD) effective in:

– Improving teaching and learning of science in schools, especially regarding pupil outcomes in science?
– Supporting schools in building their internal capacity for leading and teaching science and establishing themselves as effective professional learning communities (PLCs)?

To answer these questions, we have examined two examples of PD programmes for primary schools facilitated by the NSLN which are reasonably close to the two PD engagement models and for which we have access to considerable data. They will be presented in the methodology section.

Research Background

In this research we have drawn on the theoretical principles underpinning effective and transformative PD (Cordingley and Bell 2012; Timperley et al. 2007) and effective professional learning communities (Lofthouse and Thomas 2015; Stoll and Kools 2017). We have used these ideas when analysing the effectiveness of the two forms of PD and in drawing comparisons and conclusions.

Systematic research reviews (Coe et al. 2014; Cordingley et al. 2015, 2018) generally concur on the specific design and content features that are present in effective PD:

- Focused on 'improving and evaluating student outcomes'
- Based on robust research and provided access to specialist (usually external) expertise
- Subject-specific and with explicit support for 'translating' the learning to practice and evaluating the outcomes
- Relevant to the needs of individual teachers and organisations
- Continuous and sustainable, enabling teachers to focus strategically on particular areas of learning and practice and make links across various PD activities they do
- Conducive to teachers becoming active learners able to critically engage with the learning, experiment and reflect on it
- Encouraging peer support, collegial learning and practice
- Prioritised and modelled by school leadership

These principles of effective PD make an important contribution to the theoretical framework for our comparative research, yet there is a need for a wider perspective. We need to look at the relationship between effective PD and the school cultural and the organisational context in which the PD and subsequent implementation occurs. There is a tacit assumption that effective PD is conducive to school development: however, the relationship to school improvement remains unclear. To answer our second research question on how different PD models affect school capacity for self-improvement, we draw on the literature of 'schools as a learning community', making an explicit connection between PD and the school learning culture.

The school self-improvement movement requires schools to become learning organisations (SLO), to build up their internal capacity to change and adapt to new environments and circumstances (Stoll and Kools 2017: 7). To understand what makes schools and school partnerships effective and impactful, we draw on Stoll and Kools' (2017) integrated model of a SLO which offers the following characteristics of an effective professional learning community (PLC):

- A shared vision centred on the learning of all students
- Continuous PD opportunities for all staff
- Team learning and collaboration among staff
- A culture of inquiry, innovation and exploration
- A system for collecting and exchanging knowledge and learning
- Drawing on external (including subject-specific) expertise and linking to larger learning system
- Modelling and growing learning leadership (from Stoll and Kools 2017)

This model helps us to understand how individual experiences of PD are influenced by the existing school culture, organisation of work and working relationships (Eraut 2007). We have taken into account this model together with the principles of effective PD outlined above, to construct a framework for analysing how different engagement models of PD interact with and influence school learning culture, creating distinct enablers, while focused on improving outcomes for young people. For PD to be impactful and effective, professional learning for teachers has to:

- Be relevant to their individual professional needs as well as the need of the whole organisation
- Develop subject-specific content and pedagogical knowledge
- Draw on external expertise and evidence from research and best practice
- continuous and collaborative
- Include reflection, evaluation and support for implementation
- Model and grow learning leadership
- Nurture a shared vision of growth and self-improvement as well as a culture of inquiry, exploration and innovation

Schools differ greatly in their ability to plan and manage PD for their staff, and different models of PD delivery have different strengths and weaknesses in facilitating effective professional learning, implementation and school self-improvement.

For instance, PD which addresses the needs collaboratively identified by the teachers and leaders in a school is more likely to bring about cultural change within a school, especially if it is high-quality PD focused on enabling teachers to be reflective and actively involved in bringing about change to their practices across the school. School-led collaborative PD often has these features. Externally provided PD often starts from a different premise: it is designed to address an individual teacher's needs such as increasing subject content knowledge or introducing new pedagogical approaches. However, if it is unconnected to school priorities/organisational culture, its impact can be significantly reduced unless there is a commitment within the organisation to support changes in teachers' practice post-PD. PD facilitated by external subject experts, either during in-school-facilitated PD or external PD, can often become a transformative experience, which improves teacher subject or pedagogical knowledge and also changes 'hearts and minds'. PD can be effective in changing school culture and practices, developing effective professional learning communities and self-improving systems, when teachers are supported to work together to address their practice (in the case of school-based collaborative PD) or are supported to cascade their learning to colleagues (in the case of external PD).

Methodology

Programme Background

This comparative study focuses on two programmes of science-specific PD support for primary schools in England which, while sharing certain core features of effective PD outlined above, are very distinct in terms of the model of PD engagement that they utilise. Both programmes are facilitated by NSLN and are focused on improving the quality of science/STEM teaching and learning for the participating schools.

The first example, the ENTHUSE Partnership Programme (EPP) is a school-led collaborative PD model which encourages local schools to work together to provide subject-specific PD across a group of schools. The second example, the Primary Science Leadership Programme (PSLP), is an externally led PD model of engagement facilitated by PD tutors, who are specialists in primary science education, and it is designed to meet the needs of individual primary teachers who are new or aspire to become subject leaders in their schools.

ENTHUSE Partnership Programme (EPP)

This PD programme is a 2-year school-led programme of subject-specific PD across partnerships of four to eight schools wishing to work together to raise aspirations and achievement in STEM subjects. This PD draws on and incorporates the idea of

a developing a 'learning organisation'. The schools choose the focus of their partnership which has to be broadly linked to local issues of underachievement and raising pupil aspirations in STEM. Each partnership has a lead school, while each partner school has their own lead teacher who manages their input to the partnership.

Funding provided by the NSLN covers internal PD in the partnership, access to education experts, and external PD through the NSLN, access to online community groups and quality-assured resources.

The EPP began in September 2014 and continues to recruit partnerships at regular intervals. It has supported 429 schools (298 primary) across 70 partnerships. This chapter focuses on data from the first three cohorts of partnerships (22 partnerships comprising 104 primary schools) but also draws from the relevant data from cohort four schools (7 partnerships, 43 primary schools).

Primary Science Leadership Programme (PSLP)

The programme is an intensive residential science-specific PD for new or aspiring primary science leaders aiming to improve their subject knowledge, classroom practice and subject leadership skills. Led by experienced primary science PD tutors, this leadership programme includes nine face-to-face days over three residential periods at the National Science Learning Centre (NSLC) in York. The content and structure of PD is quality assured and includes 'gap tasks' that participants carry out in their teaching and feedback during subsequent sessions. They also design their own 'action plans', which support the application and cascading of the new learning as well as impact evaluation.

The PSLP began in 2012 and has since engaged with over 150 primary school teachers from across England. Data here focuses on the participants who undertook the PSLP during 2014–2015 (N = 60), a similar starting date for the data as the EPP.

Data Overview

This study draws from a range of impact and attainment data and evaluation tools which are summarised in Table 1. To enable data and method triangulation and to offset methodological limitations including small n-size sample or minor differences in data collection methodologies, we use a range of sources of qualitative and quantitative data, including comparative data from participants in other PD primary science-specific courses at the NSLC.

Overall, the instruments used for data collection are broadly similar; questionnaires and feedback on PD from participating teachers and leaders, reports on short- and long-term impact participants', interviews, teacher testimonies and observations of PD session by external evaluators. In addition, this research uses monitoring data

Table 1 Primary and secondary data used in the research

Data sources	EPP	PSLP
Data on quality and impact of programme collected by internal evaluation tools (conducted by NSLN)	Internal evaluation data	Data collected through internal evaluation:
	PD participant feedback forms from school-to-school PD (n = 57) and externally delivered PD (n = 28)	
Data on quality and impact of programme collected by external evaluators (conducted by an independent evaluator)	Data collected by the external evaluator (CUREE):	Teacher impact survey June 2015 (n = 36)
	Teacher survey (N = 82)	Observation of 5 PD sessions at the NSLC
	School Leader Survey (N = 29)	Semi-structured interviews with course participants (n = 12)
	Partnership Leaders' Survey (n = 51)	PD participant feedback forms (n = 113)
	Case studies (CUREE 2017b)	
	Final evaluation report (CUREE 2017a)	
Teacher assessment of pupil attainment and progress using a common data collection tool	556 records from a sample of cohort 1 and 2(Cohort 3 data was not available in time for the research) partnership schools (n = 18)	344 records from a sample of programme participants (n = 13)
Reflective participant evaluation tools (Tools are embedded into the PD to support participants' learning, action planning, and impact evaluation – based on Guskey (2000) principles of evaluating PD)	Data from individual participants:	Data from individual participants:
	Post-PD impact reports (n = 18)	Action plans (n = 24)
	Partnership documents:	Post-PD impact reports (n = 59)
	Action plans completed by school leads (n = 22)	'Champagne moments' participants' written testimonies reflecting on impact (n = 39)
	Qualitative progress reports updated termly by partnership leads (n = 20)	

from termly programme progress reports, data and findings from the EPP external evaluation (CUREE 2017a, b).

School Comparisons

We used nationally available school data to compare the background of schools participating in both programmes. Lead schools involved in the EPP show more positive national inspectorate ratings compared with EPP partner schools and PSLP

schools. Both EPP partner schools and PSLP schools show national inspectorate ratings similar to the national average. This is unsurprising as EPP schools leading their partnerships are required to have strong leadership in STEM subjects to be part of the programme. Pupil attainment for schools in both the EPP and PSLP is marginally above the national average; however the deprivation index of these schools is significantly greater than the national average.

Taken together, this suggests the schools engaged with either the EPP or PSLP are based in areas with high levels of deprivation but, in terms of attainment and inspection data, are performing in line with or slightly above the national average. It is, however, worth noting that national school data of this type is not subject-specific; hence while the school itself may be performing above the national average, this data does not provide a targeted insight into the relevant aspects of science teaching and learning, which may be underperforming. Furthermore, this data provides a snapshot of the information regarding schools at the start of their engagement with the programme and does not show trends over time. For example, while schools engaged with the EPP and PSLP are performing slightly above the national average, trend data over time may show that these schools are in decline and are therefore seeking support to address this.

There are noticeable differences in the level of individual educators who drive the engagement of their schools with each of the programmes. PSLP participants are classroom teachers who have, or aspire to have, responsibilities for leading science; they are passionate about science and are strongly focused on improving science teaching and learning. They are reliant on senior leaders to help disseminate and implement changes across the school post-PD. The EPP is driven by senior leaders who are concerned with school improvement across all subjects. They have authority to initiate changes and join the partnership, and often view science as a temporal focus, a means to access funding and support. Around half of the partnerships have a previous history of collaboration, usually in non-science subjects, while the rest are new partnerships.

Comparing Programme Delivery, Outcomes and Impact

Delivery and Quality

Feedback from PSLP participants is overwhelmingly positive with over 98% reporting good or very good quality of training (the top two ratings on a four-point scale). Participants report that the training balances good subject learning with theoretical insights, practical advice and leadership skills:

> I have gained considerable confidence as a Science subject leader and the course has provided a structure within which to lead the subject successfully and also ensure the remainder of the teaching team are confident in teaching Science and have the necessary support. The course, so far, will definitely help me to improve certain aspects of science throughout the school. (PSLP evaluation form)

However, when invited to reflect on post-PD actions and the impact achieved, participants frequently talk about challenges acknowledging the importance of securing buy-in from colleagues and senior leaders:

> [I need to] be assertive with leaders about the value of the concepts and skills gained through this training, in supporting learning in science and other areas of the curriculum. (PSLP impact report)

EPP schools draw on internal and external subject expertise. Their PD focused on subject knowledge, pedagogy, leadership, curriculum planning or joint pupil activities. EPP participants are eligible (but until recently were not required) to attend external subject-specific PD at NSLC. The programme evaluation data clearly indicates that the dispersed nature of the school-led collaborative model has challenges in supporting consistently good quality PD. The analysis of a sample of PD evaluation forms showed that only 89% of participants rated the PD as good or very good, while 11% rated it satisfactory (the second lowest rating), indicating some school-to-school CPD sessions were viewed by participants as less effective and impactful. However, when teachers on the EPP attended sessions delivered by experienced PD tutors from NSLN, their feedback on PD quality was similar to teachers attending other PD similar to PSLP at the NSLC.

Schools working in a partnership face challenges in the coordination of their PD: different priorities and timescales, different agendas and unequal input from schools across the partnership. Analysis of the programme data indicates that it is quite common for partnerships to experience setup delays and organisational problems, related to a lack of established processes for interschool collaboration:

> Less CPD has taken place due to delay caused by OFSTED inspection in lead school & communication difficulties with local SLP. All original 8 partnership schools committed to project but limited CPD so far due to communication difficulties …. (EPP progress report)

The EPP provides schools with expert coaches to support the programme; these coaches report that most partnerships need support in the management and delivery of the programme as well as support to bring all the schools on board particularly where there is no history of working together.

Impact on Teachers

We compared the survey data reported by the EPP external evaluator and impact data from the PSLP to the data reported by other participants of external subject-specific PD for primary teachers at the NSLC. We also drew from qualitative data, e.g. interviews, case studies and partnership progress reports.

Overall, there is some positive impact reported by participants across the programmes on subject content knowledge, pedagogical content knowledge and particularly on enthusiasm and confidence in teaching of science. Yet, there are some notable differences (see Fig. 1).
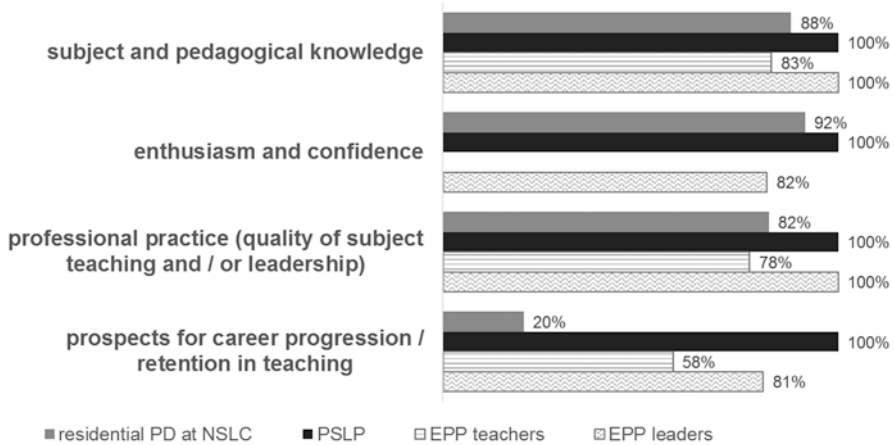
Fig. 1 Impact on science teaching reported by teachers and leaders of EPP, PSLP participants and those who attended other residential PD for primary teachers at the NSLC. Note: EPP teachers were not asked about the impact on their enthusiasm and confidence to teach science

There is difference in the impact on subject and pedagogical knowledge reported by EPP partnership leaders (100%) and EPP classroom teachers (83%) (CUREE 2017a: 6) which could be attributed to two factors; partnership leads attended more PD sessions than other teachers in partnership schools, and they also had high-quality PD from externally led experts at NSLC. The impact on subject and pedagogical knowledge on classroom teachers in EPP (83%) is more similar to the impact reported by classroom teachers of primary science PD at the NSLC (88%) but less than the impact reported by PSLP participants (100%):

> It has made me think harder in science lessons to make sure all children have practical experiences of science - moving away completely from using worksheets and taking opportunities whenever they occur, for example, the solar eclipse this year. […] Being on this course has really raised the profile of science at our school, which had been very low. I have initiated lots of new projects… winning £1000 from Rolls Royce, improving action planning, more practical hands on experience for children. (PSLP impact report)

In the EPP, 100% of the surveyed school leaders and 78% of teachers reported the changes in their teaching practice as a direct impact of the programme with the most important being 'a shift towards fostering rich scientific enquiry and a more practical approach to science' (CUREE 2017a:16). Qualitative data sources (e.g. teacher impact and partnership progress reports) provide evidence from both programmes: there is impact on the teaching of science, making it more exciting and using practical activities that foster rich scientific enquiry and development of scientific and other relevant skills.

Fifty-eight percent of EPP teachers and 81% of leaders in the EPP report an increase in their motivation to stay in teaching and better prospects for career progression compared with only around 20% of participants on other primary science PD at NSLC. This is a very significant difference, which could be attributed to the

collaborative and local nature of professional learning and its transformative impact on school culture:

> All schools have reported that the targeted CPD has had a massive influence on teacher's enthusiasm, confidence and subject knowledge in science. All teacher involved are teaching through working scientifically. (Progress Report from Lead EPP School)

Many EPP schools increase their engagement with (local) STEM employers which helps them learn about the use and applications of STEM concepts: 53% of EPP teachers and 70% of EPP leaders report improved understanding of the application of STEM in employment and how to use it to contextualise teaching. This is considerably higher than in other external PD for teachers at the NSLC where about 37% report improvement in using contextualisation in their teaching of STEM subjects.

Impact on Pupils

Both programmes had evidence showing that changes in teaching practice led to positive changes in pupil outcomes: 90% or more of participants in both programmes observed increased enthusiasm, motivation and confidence in pupils, which, according to many teacher testimonies, became a catalyst for an increase in attainment and subsequently aspirations for future careers or study. Schools reported organising whole-school events to celebrate science and its achievements which galvanised pupils' interest and engagement in STEM. Figure 2 and a quote provide an illustration of such an activity taken place in a partnership school:

> Each year, the Mary Elton partnership run a STEM project during Science Week. …In 2017, pupils arrived at school in the morning to find spacecraft debris covering the field and the area being guarded by police and the fire service. This led to the 2017 Stomp Rockets competition. (CUREE 2017a:1)

Teachers on both programmes collated attainment data on a sample of the pupils at the beginning of the programme and end of that academic year. At the beginning of each programme, teachers were also asked to use pupils' prior attainment and their professional experience of national standards to predict student performance by the end of that academic year. Figure 3 shows how teachers from both programmes assessed their pupils.

Teachers in the PSLP stated a larger positive change in the proportion of pupils working at the expected levels or above compared with those involved in the EPP. Indeed, the PSLP teachers' assessment of science attainment outperformed their expectations, with more pupils working above and less working at or below the expected level. There was significant improvement for the lower-achieving pupils: by July 2015 more than half of the lower-achieving pupils in the PSLP sample improved their attainment compared with only 18% of pupils in the EPP sample.

This finding is consistent with the differences between the programmes in the planning and implementation of PD. PSLP has fixed schedule and content CPD, including 'gap tasks' that stimulate participants to implement newly acquired prac-

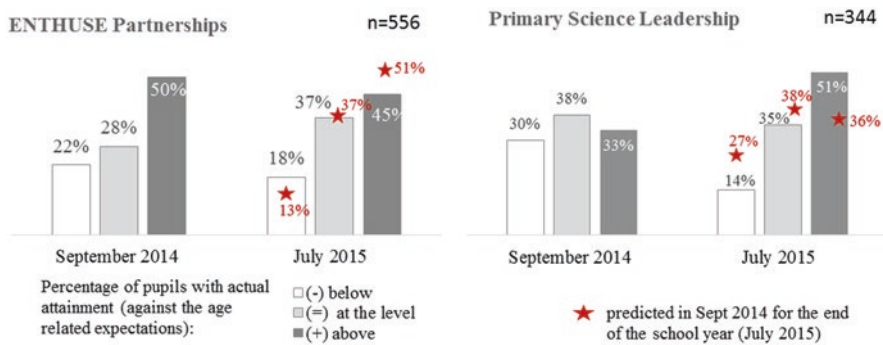**Fig. 2** Example of an enthusing STEM activity organised by a school partnership

Fig. 3 Pupil attainment data provided by course participants showing percentage of pupils working below, above or at the expected level for their age group and in relation to predicted levels of attainment. (In 2012, the national testing of pupils aged 11 in science was abolished. Consequently since 2013, unmoderated teacher assessment has been the only measure of pupils' attainment level to indicate whether a pupil is working above, below or in line with the expectations set out for children of that age.)

tices between sessions; EPP has more flexible schedule for PD and pupil activities, which, while responding to teachers' perceived needs, may delay implementation (at least in the short term) and reduce the impact on attainment. However, there may be another factor at play. The PSLP attainment data comes from the small number of pupils directly taught by programme participant; in contrast, the EPP attainment data reflects all the pupils in the school, most of whom were taught by teachers with various levels of engagement in the programme.
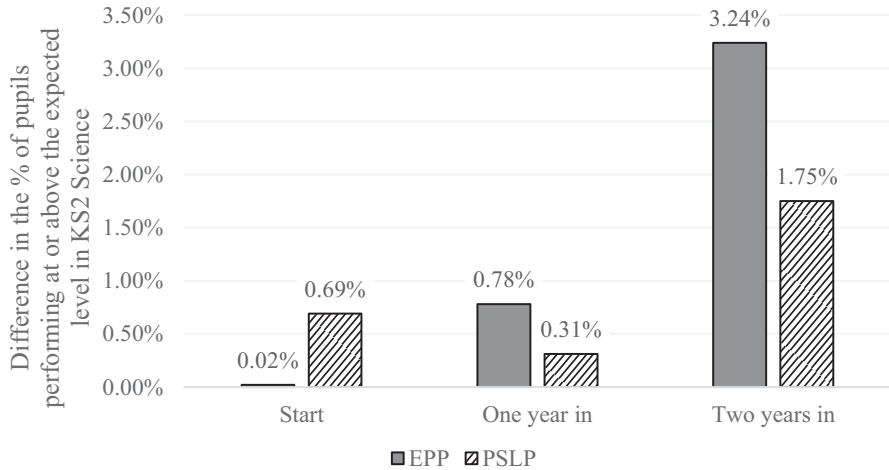
Fig. 4 The difference between primary schools engaged and not engaged with the EPP and PSLP in % of KS2 pupils performing above or at the expected level in KS2 teacher-assessed science

We also examined the impact on attainment at a whole-school level by analysing attainment data made available by the English Department for Education.[2] Similar to above, nationally available school data shows, for each school, the proportion of pupils who are working at or above age-related expectations. While the comparison of short-term attainment data from a sample of school pupils revealed a greater impact achieved by PSLP schools, the picture was reversed when we look at the national attainment data for year 6 (pupils aged 11).

We compared 'teacher-assessed science' results in schools engaged in the programmes to similar schools not engaged with either programme[3] (Fig. 4). Engaged schools were matched to non-engaged schools on four aspects recorded at the beginning of the programme:

- Science attainment
- Level of local area deprivation
- Proportion of pupils from a disadvantaged background
- Overall effectiveness rating from Ofsted

Schools engaged with the EPP show increases in the proportion of children performing at or above the expected level in science attainment compared with similar non-engaged schools. After 1 year of the EPP, there is a small positive difference (M = 0.78%) in pupils' attainment, which grows to a larger, significant difference (M = 3.24%) 2 years into the EPP. PSLP schools again show a small, positive dif-

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[2] https://www.compare-school-performance.service.gov.uk/download-data

[3] However they may be engaged in other PD. The NSLN engages with 75% of primary schools in England in a variety of ways.

ference (0.31%) 1 year into the programme, which grows to a larger positive difference (1.75%) 2 years after the programme began.

The nationally available attainment data suggests that (a) the EPP shows a greater impact on school-level attainment over the course of the programme and beyond and (b) the PSLP shows less school-level impact in the year after the programme has been completed. The number of pupils impacted from each PD could account for some of these differences, but they can also be explained by the various types of PD: the PSLP is a leadership programme in which, as the literature indicates, leadership PD takes time to cascade to colleagues' practice and therefore impact on a wider range of pupils in a school.

Wider Impact

School-to-School Collaboration

Between the two programme examples, there is considerable difference in the extent of school-to-school collaboration. Within the PSLP, 78% of teachers reported increasing their collaboration with other primary schools, and 54% had more links with local secondary schools. However, only about a third of participants reported sharing the new learning with other schools. Collaboration is at the core of the EPP: 66% of teachers, 90% of school leaders and 92% of partnership leaders reported increased collaboration with other schools.

> All schools have worked together and created strong partnerships to further science teaching. Particularly successful was the Shared Practice Days where partnership schools were paired with another to plan and team teach one or two science sessions focusing on working scientifically. (Progress Report from Lead EPP School)

Sustainability

The teachers in the PSLP initially report considerable impact, but this declines slightly over 3 years. A follow-up survey in April 2018 of teachers who had completed the PSLP in 2014/2015 showed that teachers continued to enjoy positive impact on their knowledge and practice and the pupils they teach. Yet, their success in implementing long-lasting changes across the school was more variable. On average they reported implementing at least half of their intended action plans, but in some cases the experience was less positive:

> I have been unable to fully implement ideas due to being absent due to stress and I am no longer Science lead. (PSLP sustainability survey)

When reporting on impact at the end of the PD course in 2015, all PSLP teachers said that science became a priority in their schools. Three years after the course, five

out of six respondents said that the status of science in the schools had declined and that it is currently lower than English or maths. Some, but not all, of this could be attributed to the changes nationally in the status of science in the primary curriculum. Nevertheless, the reported impact on pupils, particularly on their enjoyment and engagement in science, was still high: two thirds of teachers confirmed that their pupils were enjoying science more than other subjects. This was firmly attributed to improvements in teaching practice achieved through the course:

> We make sure that Science is as practical as possible, ensuring that learners are not faced bogged down by writing and have opportunities to develop their literacy skills and demonstrate their understanding.

> As more Science can be practical, the children can seem more confident at times to explore new things and learn from misconceptions. (PSLP sustainability survey respondents).

How does it compare to EPP? According to the external evaluation report, 'partnerships were found to be highly resilient to changes in personnel and challenges around staff turnover [and] even created opportunities for further leadership development' (CUREE 2017a: 6). Seventy-four percent of partnership leaders agreed that their partnership's activities and impact would be maintained if they or other key personnel were to leave.

The evaluators observed that 'success of partnership activities and the increased profile of science within the school helped, sometimes initially less committed, headteachers to see the value in investing in science and committing more resources to match or replace the EPP funding in successive years' (CUREE 2017a: 18). Increased visibility of science and the status of a school partnership enabled some of them to successfully establish links with local businesses and seek alternative sources of funding. This expanded the scale and range of partnership activities during the EPP funding and added to their overall sustainability after the end of the funding. For instance, one partnership of six primary schools, which had a history of collaboration as well as some links to local employers, was able to significantly expand their collaborative work, acquire more financial and in-kind support from the local employers and engage more nearby schools and pupils:

> Drawing on both external and internal expertise has been integral to the success of the partnership. Supported by external STEM experts, their teachers and other pupils, the children can see the practical value and application of STEM subjects. …They meet and work with pupils from other schools and learn about the wider issues linked to each project.

> It is has been possible to develop existing and new links with external STEM experts to support professional learning. One existing link was with the local engineer … who was involved in the construction of the Wimbledon centre court retractable roof. The ENTHUSE funding supported him taking a wider role to demonstrate engineering techniques and concepts to both teachers and pupils as part of the annual competitions. (Mary Elton Group Case Study: CUREE 2017a)

A survey (March 2018) of the partnerships involved in the programme between September 2014 and July 2017 investigated the longer-term impact and sustainability of the programme. There are indications that schools continue to capitalise on

what they achieved in the programme, particularly in terms of the quality of science teaching and learning. Schools report numerous 'legacies' benefiting teachers and pupils, which range from 'teaching science in an engaging way' to 'improving the status of science in school' to 'raising science attainments' for groups of pupils with disadvantaged background like 'girls from a specific minority group'.

Partnership schools reported sustained positive changes as well as continuing to carry out joint activities with other schools in the partnership (83%) and continuing to benefit from working together. However, all partnership leads responding to the survey stated that the lack of further funding was a significant barrier to sustainability, so many had to scale down their collaborations:

> We've continued to meet once per term and ran training where all the schools came together. We've also shared equipment, run science days and events across the ENTHUSE schools. (EPP sustainability survey respondent)

That said, five out of the six sampled partnerships were able to retain most schools in the original partnership with two managing to add new schools to their membership:

> We are carrying forward practice, skills and knowledge gained from our work with ENTHUSE supported by acknowledgement of The Wellcome Trust Awards. We are now leading a group of 20 schools on a 2017 project on rockets called 'Looking out to space – looking back to Earth'. What may be useful to know is that there is legacy [C]PD impact [...] in our case, we are continuing not only to impact within our schools but are creating our own outreach [C]PD too, which will be even more [C]PD […] and that 'bang for your buck' has not stopped once the project is over. (EPP sustainability survey respondent)

This enabled cascading good practice and impact from the programme participants to new teachers, pupils and schools:

> [The EPP] has given us the foundation to build on. Science teaching as a curriculum area is working well and we can now focus on the other STEM areas through real-life problem solving for the children. (EPP sustainability survey respondent)

Discussion

To answer our research questions about the impact of the two different PD engagement models and their relative advantages and shortcomings, it is useful to map them against the combined framework of what makes effective PD (Cordingley et al. 2015) and effective learning communities (Stoll and Kools 2017), which was outlined at the start of the chapter.

As exemplars of the two PD engagement models (school-led collaborative science-specific PD and external PD for science leaders), both programmes analysed in this study (EPP and PSLP) cover at least some of these eight areas of effective PD and learning communities. They both aim to improve outcomes for young people and develop subject-specific content and pedagogical knowledge; are continuous PD; include reflection, evaluation and support implementation; and model

and grow learning leadership. They are relevant to either the individual teachers' needs (PSLP) or the whole school's needs (EPP). They have differing levels of collaboration, diverse ways of drawing on external expertise and evidence from research and best practice and develop visions for growth and self-improvement in different ways and contexts.

The evidence shows that both models of PD engagement have merits and issues, with differing levels of resilience to support school improvement. The motivation behind the people who drive school participation in subject-specific PD is different, which affects the implementation and the impact. PSLP participants are (new or aspiring) subject leaders, and science teaching is their passion. They often report considerable success in improving their own teaching and outcomes for their own pupils, with some success in cascading their learning to colleagues and inspiring them to make changes in their practice. However, sometimes they encounter indifference or even resistance from colleagues including lack of support from school leaders which can reduce the impact of the PD outside of their own classroom.

In the EPP, senior leaders are the driving force and the strategic enablers of change, with the actual implementation falling on subject leaders and classroom teachers. The impact of the PD is stronger when the whole school is on-board, when they acquire a sense of ownership of the project and become willing and active collaborators (Watson 2014). However, this does not happen automatically, and the success depends on the willingness, ability and capacity of the rest of the team as well as on whether they are encouraged to work 'together' towards a shared common goal, not just commanded working 'with' (Lofthouse and Thomas 2015). The EPP experienced additional organisational obstacles and issues related to collaborative work, such as agreeing aims or priorities of actions, which can cause delays and issues with the start-up and implementation of a partnership. This is particularly common among the newly formed partnerships that have yet to establish working practices in their collaboration, without additional guidance and support.

While science or another STEM subject is the focus of an ENTHUSE Partnership, for senior leaders it is often just one of the many school priorities. There is evidence that programme can be derailed before it is fully embedded unless there is an effective senior member of staff to lead it forward. Yet, the sustainability data collected within this research gives a reason for optimism. Although the lack of a focused perspective on science can be an obstacle at the start of the EPP, the broader vision of how a school partnership in science/STEM can act as a vehicle for whole-school improvement adds to its resilience and sustainability after the funding ends.

Since working in a partnership requires schools to build their leadership capacity, this gives additional opportunities for leadership training, to observe and work with leaders from other institutions (Hadfield and Chapman 2009). This is certainly an advantage of the partnership model; however the evidence indicates that unless the leadership training draws on external expertise, research and best practice, the quality and practice of leadership may remain suboptimal. This is also the case for PD delivered by teachers to other teachers in a partnership: unless they have had training in effective PD facilitation, they are less likely to be familiar with strategies which make PD relevant, effective and impactful.

In comparison, the model of external PD for science leaders led by subject education experts enables teachers to learn from and work with expert, professional PD tutors who provide access to up-to-date knowledge and expertise in subject areas alongside effective PD practices. This intensive and immersive PD balances the learning of new subject content including cutting-edge science and pedagogical knowledge with insights into the theory of 'science of learning' (Howard-Jones et al. 2016) and with the development of reflective skills and critical analysis of how this could be applied to the teaching practice (Bolton and Delderfield 2018). The structural design of PSLP as a multi-residential course, where participants have space for learning, testing, reflecting and evaluating, gives support to effective learning. The impact is impressive gains in pupil attainment reported by PSLP participants after the first year of the programme. Data for the same period from the EPP shows less improvement in pupil outcomes, indicating that partnerships needs more time to deliver impact on pupil achievement.

Overall, in our experience PD delivered externally by professional tutors – who are often research active or at least follow research best practice – is more likely to build on the principles of effective PD and meet the learning needs and practice of individual teachers. The inclusion of a leadership component enables sharing the principles of how to lead teams as effective professional learning communities. The programme data reviewed in this research shows that the PSLP provides subject leaders with transformative experience that affects their mind-sets and practice and, as Timperley et al. (2007) suggest, makes them well equipped to become 'movers and shakers' of subject teaching and learning as exemplified in the following quotes from course participants:

> The whole course has been extremely valuable in extending my subject knowledge and in leading science in school. I have taken away some great ideas that I can use in the classroom & suggest to colleagues.

> I have developed the confidence to support colleagues and have implemented a new scheme of work and assessment system for science. I have raised the profile of the subject because of my improved enthusiasm. (PSLP impact reports)

This is a transformative experience for individual teachers, but because it happens outside the school, it can limit the embedding of the learning, thus limiting the scale and sustainability of the impact on the leadership, teaching and learning of the science in the school. The effectiveness of this PD model in supporting school improvement relies on the personal qualities and capability of participants to act as change agents. This type of PD has lower resilience to changes within the school, including changes to personnel particularly at the headship level, change in school priorities, culture or other circumstances. We have evidence of limited impact on school improvement when participating teachers change roles, move to a new school or go on maternity leave, or if a new school head brought in new priorities and management styles. All of these scenarios negatively affect the scale of implementation and reduce the ability of these newly trained leaders to embed system-level improvements. The PSLP experience indicates that these vulnerabilities can be partially

alleviated through embedding leadership skills alongside the subject and pedagogical knowledge.

In contrast, the school-led collaborative model can accommodate some aspects of effective PD which are more difficult to achieve in externally led PD. It is able to focus on collegiality, providing an impetus for nurturing and sustaining a shared vision of growth and self-improvement (Kruse and Seashore 2007) as well as developing a culture of inquiry, exploration and innovation (Stoll and Kools 2017). There is evidence that this has an immediate noticeable effect on teacher motivation to stay in the profession and on career progression for those leading the partnership. It can be very relevant to the need of the whole organisation; however often leaders report that it significantly increases their workload, which can become a limiting factor in the school capacity for self-improvement. A particular strength of this PD model is that it has a wide reach with the ability to improve teaching and learning in multiple schools in a locality, fostering links to local experts, communities and STEM employers, thus creating a more durable infrastructure for strong and effective professional learning communities (Armstrong 2015).

Conclusion

The purpose of this comparative study was to investigate the effectiveness of two PD engagement models in improving leadership, teaching and learning of science in English primary schools. We compared the design, delivery and evidence from two programmes of subject-specific PD, the ENTHUSE Partnership Programme and Primary Science Leadership Programme, as exemplars of the engagement models. To ascertain their effectiveness, we examined the outcomes of the programmes against the theoretical principles underpinning effective PD and those of schools as learning communities.

Both exemplar programmes were found to be successful in terms of improving the leadership, teaching and learning of science with some evidence of impact on pupil outcomes, partly explained by some common features of each programme. However, there were key differences in the programmes which led to different challenges and advantages and consequently differing types of impact. The strength of PSLP is that it incorporates high-quality external expertise in the content and delivery of PD providing individual teachers with the motivation and skills to improve their teaching and outcomes for pupils in their classes. However, the major issue is that because it is delivered externally to the school, it is not always as effective on the leadership of science, changing colleagues' practice and hence impacting on pupil outcomes throughout the school over a period of time. The partnership model has the opposite issue: it has a potential to create an infrastructure for collegial learning throughout and across schools to improve the leadership and teaching of the subject; however unless this model is supported with strong input from external experts, research and effective practice, the potential of impact on outcomes for pupils are not guaranteed.

A good understanding of the advantages of these PD engagement models can be used to develop delivery models, tackle their limitations and reinforce their stronger features. The NSLN has consequently revised the design and delivery of the two programmes discussed in this paper trialling a more 'blended' approach of PD engagement combining the stronger elements of each programme. Consequently since 2017, all EPP schools are required to engage with at least one externally led residential PD at the National STEM Learning Centre, enabling teachers to access work placements in industry or academia and engage with the STEM Ambassadors programme to support career education and contextual learning. The PSLP is further supporting participants in the development of effective strategies for embedding and cascading their learnings across their school. They are actively encouraged to increase their collaboration with local schools, using funding opportunities and programmes provided by NSLN and its partners. It will need several years to ascertain the impact of these changes on each programme, but the feedback from participants of both programmes looks very positive.

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A Design-Based Process in Characterizing Experienced Teachers' Formative Assessment Enactment in Science Classrooms

Hannah Sevian and **Vesal Dini**

Introduction

The initiation-response-evaluation (IRE) discourse pattern in classrooms is pervasive and well documented (Mehan 1979). In this pattern, the teacher initiates a question, students respond, and then the teacher evaluates this response. In spite of extensive science education reform efforts over decades, and the implementation of a wide variety of highly developed hands-on science curricula, studies have repeatedly shown that the IRE pattern persists and classroom science learning remains largely procedural without challenging students to make sense of what they are learning (Banilower et al. 2013; Roth and Garnier 2007). Compounding this problem is that many experienced science teachers consider that their teaching is well aligned with high levels of inquiry in their classrooms. Teachers report engaging their students in questioning, modeling, and communicating evidence several times per month, yet observations reveal that the teachers' definitions of inquiry vary and they often map their classroom practices onto vague notions of inquiry activity (Capps et al. 2016). In fact, it is rare that sense-making activities for students get connected to laboratory-based activities in the classroom and discourse in classrooms that promotes such sense-making is even more rare (Weiss et al. 2003). These persistent problems suggest that teachers could benefit from practical tools to help them attend to sense-making in science classrooms, with specific guidance for experienced teachers to reflect on their own discourse practices.

The aim of this chapter is to share our design-based research approach to addressing the following problem of practice: *There is a lack of practical guidance for science teachers in enacting formative assessment (FA) to support students' sense-making*. In an urban partnership that includes middle and high school science

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teacher leaders, school district administrators, and science education researchers (Szteinberg et al. 2014), we converged on this problem of practice that combines the perspectives of multiple stakeholders. In the statement of this problem of practice, we intend *practical* to mean based on the practices of experienced science teachers, *guidance* to mean that it is clearly defined and easy for classroom teachers to use, *enacting* to mean that it is about options that teachers can take in their instructional decisions, *support* to honor the teacher as agent in achieving the goals of learning for students, and *sense-making* to recognize that student learning benefits when students are protagonists in their learning. In the work reported here, we focus on the process among teachers and researchers that led to a resource to address our problem of practice. The resource provides guidance for experienced teachers in examining their own classroom FA practice as well as an instrument for researchers to study science teachers' FA enactment.

Design-Based Research Approach

Through this problem of practice, we seek to address important problems facing teachers working in the complex environments of science classrooms. We therefore followed the approach of design-based research (DBR), which was developed "to address theoretical questions about the nature of learning" situated in real-world contexts and "derive research findings from formative evaluation" (Collins et al. 2004: 16).

DBR assumes the entanglement of the design of a learning environment—which may take the form of an instructional approach, type of assessment, or learning activity (Anderson and Shattuck 2012)—with the development of a related learning theory (Brown 1992). DBR stipulates that such design and development should take place in naturalistic settings and be carried out in an iterative process of designing, enacting, analyzing, and redesigning (The Design-Based Research Collective 2003). In a DBR process, not only does this iterative process of design evolve, but there is also a major product goal of communicating how enactments are connected to outcomes of interest in the particular context under study. Our explanations here are crafted for the purpose of guiding fellow practitioners.

We extended our DBR approach to create what Bereiter (2014) called principled practical knowledge (PPK), which is systematic, coherent, and explanatory, but its main purpose is practical guidance. Our aim in this was to "increase the generalizability of knowledge produced through design work and provide a ladder leading to sometimes radical design improvement" (Bereiter 2014: 1). From analyzing researchers' DBR processes, Bereiter identified three stages that help put the production of PPK into context: (1) a practical observation emerging from the DBR experience; (2) a reasonably coherent and generalizable explanation of what has been observed, which may still be limited; and (3) basic research to form results

from the second stage into theory. Bereiter points to the second stage as representing PPK, "which is both a foundation for further design advances and a stimulus for theoretical research" (p. 11). We describe our DBR process in terms of Bereiter's stages. After an initial description of Stage 1 (practical observation), we concentrate on the second cycle that took place in Stage 2 (generalizable explanation), because it points toward the integration of results into theory.

Practical Observation

The current team includes five grades 6–12 science teacher leaders from different schools in a large urban school district, two school district administrators (the director and associate director of the district's science, technology, and engineering department), and three science education researchers at a public university in the same city (a chemistry professor, a physics education postdoc, and a doctoral student studying chemistry education). Some members of this team have collaborated for up to 14 years, while others more recently joined the team 2–3 years ago. Members of the team observe in each other's classrooms, both in person and through video, and design and lead professional development (PD) for science teachers and administrators in the school district as well as nationally. A 6-year history is condensed into a story of the process, aided by field notes collaboratively recorded by one of the researchers and one of the teachers.

Development of our practical observation (the product of Stage 1) took shape through several half- and full-day meetings over 1 year. The design team determined that four groups of stakeholders were necessary to forming a practical observation of *the FA practices of science teachers*: teachers, students, school district personnel, and science education researchers. Initially, we followed a process of identifying questions that the team considered to be important, and then observing critically in our own and each other's classrooms, considering how our students experienced FA, and opening discussions with colleagues about PD and resources for FA that they wished for. Our questions evolved over time as we read and discussed current research (Coffey et al. 2011; Colestock and Sherin 2015; Furtak et al. 2014; Talanquer et al. 2015) and reported on our informal investigations.

At the conclusion of this practical observation, we developed a characterization of the problem of practice at the intersection of four stakeholders' priorities. We also agreed upon a definition of FA based on our review of literature: "the process used by teachers and students to recognize and respond to student learning in order to enhance that learning, during the learning" (Bell and Cowie 2001). With reference to Talanquer et al. (2015), we identified three aspects of teachers' approaches to FA that we wanted to better understand: noticing, interpreting, and acting.

Generalizable Explanation

The design team turned next to developing cycles of validation to study the problem of practice, with the goal of creating a coherent explanation that would accomplish two aims: to strengthen theory on attending to students' sense-making and to offer specific guidance for experienced teachers to help them assess their own discourse practices in support of students' sense-making.

Focus Groups Analyzing Student Work

In our first cycle, we aimed to characterize how experienced science teachers notice and interpret students' ideas, how they propose to act on their interpretations, and how they consider FAs to make possible the enhancement of learning during the learning. Following a review of literature, we designed an approach to collecting data via focus groups of experienced chemistry teachers who analyzed students' written artifacts from an open-ended FA designed to uncover students' thinking about how to control chemical reactions. Five focus groups (23 teachers in total) discussed what the teachers paid attention to in the student work, how they interpreted it, what actions they would take based on this, and how the FA could be improved to better capture students' thinking. Analysis of the focus group data resulted in an initial model (Fig. 1) of FA enactment that characterized how teachers evaluate student thinking and plan actions based upon their evaluation (Clinchot et al. 2017). In this model, the teacher initially notices student thinking, either in a descriptive or inferential manner. Next, the teacher interprets what is noticed, either with an evaluative or interpretive approach. Finally, the teacher acts upon what has been interpreted, either by remediating to correct errors or by responding to the disciplinary content in students' thinking.

Outcomes of this first cycle included that it is productive to define scales within noticing, interpreting, and acting, as others have done (Lineback 2015; Talanquer et al. 2015). We found that the teachers' positions on these scales tended to occur in clusters, and we formed four composite "FA personalities" of the most prevalent clusters (Clinchot et al. 2017). These analyses led us to recognize that noticing and interpreting are closely linked and difficult to analyze separately.
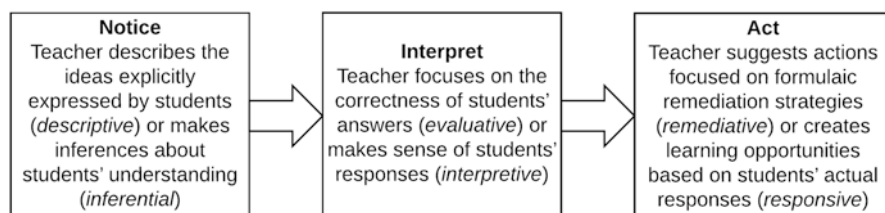

Fig. 1 Initial model of formative assessment enactment

Development of an FA Enactment Resource

In our second cycle, we focused on how FA is enacted by teachers in their classrooms. We expanded the process to include more informants, including the design team, 9 teachers who participated in a 6-month series of PD workshops, and 42 science teacher leaders who participated in a 2-day retreat. We carried out this cycle in a back-and-forth process that oscillated among using the emerging resource to develop and lead PD, collecting data in teachers' classrooms, asking teachers to use the developing resource to analyze their own videos, and further developing the resource through analysis of classroom videos and analysis of field notes from PD. We describe the product of this cycle and how it emerged via four phases. The phases are not design iterations, i.e., they were not marked by articulations of findings in relation to the problem of practice. Rather, the phases are marked by advancements in critical elements of the design-based process, especially the complexities, challenges, and major learnings in each phase (Collins et al. 2004).

Phase 1: The Design Team's Beginning FA Enactment Model

During the first and longest phase, the design team focused on forming an initial FA enactment resource and planning for a district-level PD that would serve to test its usefulness. This work took place at monthly entire-group meetings, as well as more frequent meetings of the researchers in between.

At the beginning, we clarified our understanding around the purpose of FA to ensure common grounding. We built from Bell and Cowie (2001) who specify that FA enhances learning during the learning process. This pushed us to examine classroom discourse (Lemke 1990). As a way to gather experience with this approach, the teacher leaders on the team video recorded FA in their own classrooms. Using these videos, the team explored the rhythm of FA as it unfolds in discourse among a teacher and students. As a way to organize the interactions, the team considered FA as moving in cycles where the teacher first elicits students' ideas, notices something about them, interprets some kind of meaning, and then acts, after which this cycle repeats (Ruiz-Primo and Furtak 2007; Windschitl et al. 2018).

The design team recognized that the PD would require attention to both domain-general (e.g., promoting claims-evidence reasoning) and domain-specific teaching (e.g., exploring the difference between melting and dissolving in chemistry). We recognized that the dimensions of our FA enactment model (noticing/interpreting and acting) could address both of these, because the way we were framing noticing/interpreting requires attention to the substance of students' thinking (Coffey et al. 2011). We first considered teacher noticing/interpreting to exist on a spectrum from evaluative (i.e., seeing student responses through a lens of correct or incorrect) to inferential (i.e., treating students' ideas as having sensible origins) (Talanquer et al. 2015) and acting to occur on a spectrum from what we called at that time prescriptive (i.e., guiding to particular ideas through directive discourse) to responsive (i.e.,

creating opportunities for proactive student thinking). As a way to investigate these in the context of classroom videos and determine parts of videos to use during the PD, researchers on the team brought several videos with transcripts from different design team teachers' classrooms. The team tried to understand the students' thinking evident in the videos and then characterize teachers' acts as prescriptive or responsive. Together, we learned it is important to begin video analysis by unpacking the sense in students' ideas so as to mitigate the urge to comment on what a teacher should have done. Starting with a scheme based on Lineback's (2015) idea of focus and activity redirections, team members proposed different teaching acts to be included under the prescriptive or responsive categories and gradually refined that list over time.

During one of our meetings involving the review of a classroom video, the team ended up in extensive discussion with the teacher about his moves and what motivated his choices. Because the teachers on the design team found this conversation valuable, we identified this approach as a useful way to learn more about PD participants' intentions and noticings. Planning ahead to Phase 3, we asked teachers who were going to participate in a 6-month PD series to video record FA in their own classrooms and conduct self-interviews about the learning goals of their FAs.

The teachers on the design team also found it very helpful to think about different types of moves a teacher could choose to make; thus we wanted to present the resource as a toolkit of choices. The teachers also appreciated that a choice depends on understanding not only the students' thinking but also the context of the thinking that they worked to unpack. For example, the teachers pointed out that there are affective aspects to supporting students' meaning making, such as affirming progress or empathizing with struggle. They also brought up contextual influences in the form of dilemmas teachers face (Windschitl 2002), such as the pedagogical dilemma of time pressure imposed by preparing students for standardized tests.

The team, however, grappled with the grain size of coding. Although coding of individual teaching moves was beneficial because it helped teachers focus on their choices in those moments, the team questioned whether line-by-line coding of noticing/interpreting would be productive in the PD. To mitigate the concern, we decided to focus on teaching moves at the extremes of the prescriptive-responsive spectrum. We chose contrasting cases of videos from the classrooms of two design team teachers. Each video demonstrated a well-executed FA activity in which students discussed open-ended chemistry problems. One teacher (Kitty) used mostly prescriptive teaching moves, and the other (Thomas) used mostly responsive teaching moves. Kitty asked students a series of leading questions in quick succession to move them to a specific idea. The students responded to the questions in short utterances, either agreeing or introducing new questions that spurred Kitty to respond in the same ways. Thomas facilitated a discussion by listening carefully to students' ideas, rephrasing them as necessary, highlighting inconsistencies, and challenging students to resolve differences.

Phase 1 was marked by the following insights: (1) it is necessary to unpack the complexities of teachers' choices behind their teaching moves beginning with

openly discussing what could be the sense behind students' ideas, and (2) focusing on clear-cut contrasting cases of the extremes of the teaching spectrum helps teachers articulate the logic behind their choices.

Phase 2: Testing the Initial FA Enactment Resource

Having worked out a preliminary FA enactment resource, the design team tested it with 42 preK-12 science teacher leaders throughout the district at a day-long retreat. The retreat was led by the design team's teacher leaders. This arrangement for facilitation was intentional because it foregrounds the agency of teachers in making decisions about their FA practices (Stroupe 2017).

The FA enactment resource was used in two main activities at this workshop to probe its usefulness in teachers first examining other teachers' FA practice, and then practicing decisions about how FA practices could be different. In the first activity, teachers experienced two engaging lessons about electrochemistry while taking the role of learners (the topic was chosen because few teachers knew it well). These lessons had deliberately designed teaching moves at prescriptive or responsive extremes. The teachers recounted their experiences as learners and then compared the teaching moves in each lesson. Considering their role as students, the prescriptive teaching moves engendered feelings of passivity and comfort in the way information was presented in a scaffolded manner. In contrast, when in the role of student, they experienced the responsive moves as animated argumentation, requiring self-reliance and peer input to figure things out, and feeling frustrated as they lingered in confusion. Imagining what it would be like to teach in each way, they likened prescriptive teaching to a teacher's ship carrying its passenger students to a destination and spoke of responsive teaching as facilitating discussion through questioning, repeating, and seeking clarification of student ideas. Teachers' descriptions of the student and teacher perspectives established that the resource would be effective in helping teachers account for both perspectives.

In the following activity, teachers worked with the two videos (of Thomas and Kitty) previously chosen. Teachers at the workshop *first* analyzed the students' thinking (saying what they noticed and interpreted) and then examined each teacher's actions using the resource that specifies different kinds of prescriptive and responsive teaching moves collected in Phase 1. Many teachers struggled to focus on identifying the sense in the students' thinking, instead gravitating toward commenting on teaching moves, the coding of which teachers found easier and more natural. This prompted the design team to consider how to better support teachers to notice/interpret in ways that attend to sense in students' thinking.

Phase 2 was marked by this insight: there is benefit in connecting learners' experiences in prescriptive vs. responsive extremes with deliberately orchestrated teaching moves.

Phase 3: Further Development of the Model in PD

The FA enactment resource, specifically the dimensions of noticing/interpreting and acting, was further tested by teachers in a full-day PD workshop during a 6-month PD program with nine K-12 science teachers. Participants used the FA enactment resource to analyze *their own* videos. The teachers were asked to video record an FA activity in their classroom from their own vantage point (using chest harnesses to which their smartphones are attached). Each 10–20-minute recording included the teacher's launch of the FA, interactions with students, and a wrap-up of the activity. Before examining their own teaching moves and those of a colleague, teachers extensively analyzed their videos for students' thinking. As a lead-in to analyzing their teaching moves, participants were first oriented to the acting portion of the FA enactment resource while looking at some of Thomas's and Kitty's moves.

We gleaned four insights from Phase 3. First, the teachers continued to be challenged to focus on the substance of student thinking in considering teaching moves and imagining other possibilities. During the first part of the workshop, which had the exclusive purpose to make sense of students' thinking, teachers primarily evaluated students' ideas as correct or incorrect. They also appeared to be much more comfortable discussing domain-general (e.g., is the student making claims and supporting with evidence) than domain-specific matters (e.g., how is the student thinking about hydrogen bonding). The design team recognized a need to better support noticing/interpreting, particularly the disciplinary substance of students' thinking (Richards and Robertson 2016). We decided for a future phase to create short video segments showing student discussion up to the point of, but not including, the teacher's move, to open space for teachers to discuss multiple possible moves based exclusively on their interpretations of student thinking. This takes advantage of teachers' inclinations to focus on teaching moves, but places emphasis on identifying evidence of students' thinking and the teacher's interpretations of it.

Second, the design team found that care must be taken to prevent dichotomous thinking with respect to teaching acts. That is, teachers perceived prescriptive teaching to be bad and responsive teaching to be good. In a concluding discussion with the teachers at the end of the workshop, participants and the design team came to the idea that the difference between the two is *who is doing the sense-making* (in prescriptive moves, sense-making is at the teacher's initiative, while in responsive moves the student is the protagonist) and that there are appropriate times to use one or the other. A benefit of first watching the videos from Thomas and Kitty was that participants engaged in examining their own videos more productively because both teachers taught effectively in the two extremes. We also recognized that there were negative connotations associated with some of the vocabulary that contributed to teachers' interpretations of the types of teaching acts. We revised wording in the model to reflect teachers' intentions for why they may intentionally choose particular actions. We changed prescriptive to directive, since the latter is more descriptive of the intention behind this type of advancing act, i.e., the teacher intends to direct students toward a particular science view.

Third, the participants were universally appreciative of the opportunity to systematically reflect and comment on their teaching moves using the FA enactment resource and of the opportunity to contribute to this resource by suggesting additions to the resources as they examined their videos. In this sense, a dual practitioner/researcher lens helped reduce the vulnerability threat in examining their classroom practice with peers. Examining each other's videos with common codes helped to lift teachers from the uniqueness of their classrooms into discussing generalized experiences across classrooms.

Fourth, during the discussions teachers had about videos that they had separately analyzed prior, most teachers elaborated on the context behind their moves. We noticed that, particularly when there were emotions (e.g., frustration, surprise, concern, joy) in the teachers' written comments about their own teaching moves, they would give contextual explanations that expanded upon ongoing issues spanning multiple lessons with particular students. We recognized an important synergy between teachers' explanations of their moves and our interpretations of them. For the research, we built in a mechanism for interviewing teachers.

Phase 4: Researchers' Refinement of the Coding Framework

The experiences of Phases 1–3 allowed researchers on the design team to analyze complementary data sources that would provide valuable perspectives on teachers' FA enactment. These sources included teachers' self-interviews about the FA activity, classroom video recordings of the activity, their analysis of specific videos within the activity, field notes taken by researchers at all PD meetings, and anonymous evaluations administered by external evaluators after each workshop. Using a well-defined process, each of the researchers on the design team systematically analyzed these data sources by documenting aspects of teachers' purposes for their FA from their self-interviews, using a coding scheme to characterize teaching moves from their classroom videos, and assessing teachers' in-the-moment purposes and noticings from their comments on videos.

The details of this analysis and findings are presented elsewhere (Dini et al. 2019); here we describe the outcomes, which included three main developments in improving the FA enactment resource. The first development related to a challenge of differentiating eliciting and advancing actions. When analyzing teaching moves, we sometimes found it difficult to discern whether the teacher's intention was to find out more about students thinking (*eliciting*) or to advance it toward canonical understanding (*advancing*).

The following exchange illustrates this issue. The teacher (codenamed Terra) is discussing with a student (codenamed D1910) differences between parallel and series circuits. The student is comparing three circuits and refers to one in which two resistors are connected in parallel with a voltage source:

1. ***D1910:*** *Doesn't the current equal each other when it's parallel (referring to the two branches after the ammeter in the circuit)?*

2. **Terra:** *So you're saying the current here equals the current here (pointing to two points in the circuit).*
3. **D1910:** *Yeah.*
4. **Terra:** *Okay. And then if you wanted to compare that current (in the circuit of interest) to this current (in another circuit), what would you get? How would you do that?*

In this moment, Terra may have intended to learn about D1910's understanding of current, but she also appears to have advanced it by implicitly requesting that D1910 provide reasoning to justify her thinking. In this sense, such a question can play a dual role of informing the teacher about a student's ideas and advancing the student's understanding of scientific practice. Terra is acting to uncover more about the student's thinking (i.e., eliciting); however, without knowing more about Terra's explicit intentions in asking the question in turn 4, it is difficult to say whether she is also trying to advance D1910's thinking.

The second development was the recognition that a FA enactment does not take place in a linear manner (Fig. 1). Rather, it takes place as complex nonlinear sequences of teacher noticing/interpreting followed by eliciting or advancing acts. The resource was modified accordingly, to guide teachers to understand the centrality of noticing/interpreting student thinking in an FA enactment, and the two kinds of acts that follow from it: eliciting or advancing (Fig. 2).

The third development was that teachers can have multiple and often simultaneous purposes while enacting a FA (e.g., developing students' content understanding, attending to students' learning processes, cultivating students' agency). Overarching purposes are often filtered by contextual influences that shift and shape teachers' in-the-moment purposes. And in-the-moment purposes can also be individualized to particular students and can grow out of specific teacher-student relationships. For instance, the same teacher (Terra) communicated an overarching aim for her FA to learn whether her students could remember and apply circuit rules to an open-ended
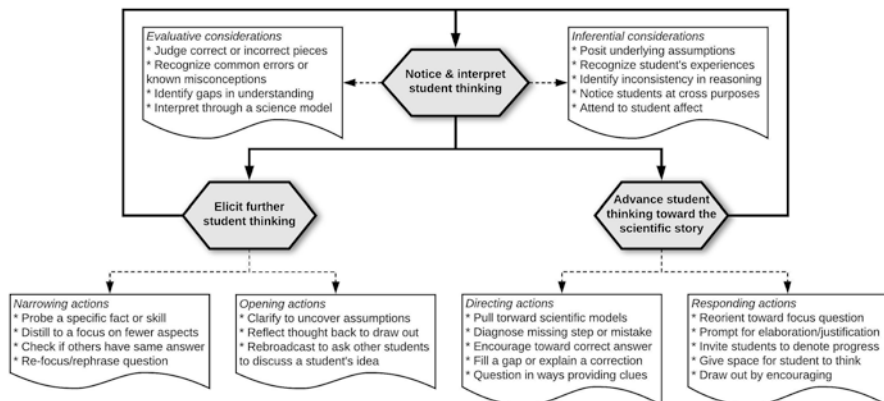

Fig. 2 A summarized version of the FA enactment resource emerging from Cycle 2

conceptual problem. In the course of interacting with one group of struggling students, Terra focused on supporting the students' reasoning. Immediately after this, she moved to another struggling group and simply explained the rule and had them move ahead on the problem from that point. In discussing this with Terra, we learned that contextual influences clearly shifted and shaped her in-the-moment purpose with each group. Terra and other teachers found the opportunity to reflect on these purposes and associated influences—often implicitly operating—very useful in learning to become more intentional about their FA practice.

Phase 4 was marked by these insights: (1) a single move can sometimes be both eliciting and advancing, (2) in-the-moment purposes shift and also shape teaching moves, and (3) a teacher's in-the-moment purposes often are specific to individual students, incorporating disciplinary content-, general-, and domain-specific processes and affect-related goals that the teacher has for the student.

Values of the Design-Based Process

The FA enactment resource was a concrete product that emerged from the PD and represents the PPK described by Bereiter (2014). Bereiter describes PPK as being both procedural and declarative. It is knowledge that is able to be "communicated symbolically, argued about, combined with other propositions to form larger structures, and so on" (p. 5). Rather than being a codification of practice, it is for the purpose of solving problems. The PD guided and opened space for teachers to focus on the substance of student thinking and reflect on their teaching acts in relation to this. The teachers imagined different possible ways of supporting their students, including in enacting different kinds of eliciting and advancing (Fig. 2). Teachers valued the FA enactment resource for the lens it provided to see and characterize their classroom discourse, and how that discourse supported or hindered student learning.

Having teachers contemplate the combination of their in-the-moment purposes and the larger purposes of their lessons supported them in understanding the decision-making around teaching acts that were often taken on a subconscious level. They appreciated that the FA enactment resource characterized the different types of actions that teachers have in their own repertoires and can employ intentionally and strategically in order to support student outcomes. In subsequent design team meetings with the district science administrators, we learned that what teachers value the most in the FA enactment resource, as well as its use in PD, is the capacity it develops in teachers to lead from the classroom.

The team's design-based process also contributed to theory on attending to students' sense-making. Rather than starting with the design of elicitation questions, as many current models of FA suggest (e.g., Ruiz-Primo and Furtak 2007; Windschitl et al. 2018), we learned that the teacher's noticing and interpreting is central to FA enactment. Honoring the teacher as the agent in achieving the goals of learning for students emerged as the most important commitment in the articulation of the

problem of practice addressed by our process. Based on this, we advance a further hypothesis that teachers can enact more intentional teaching moves when they have the power to recognize when it is beneficial for students or the teacher to be doing the sense-making in a given learning situation.

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Teachers' Training in Developing Nanoscience and Nanotechnology Teaching Modules in the Context of a Community of Learners

Giannis Sgouros and Dimitris Stavrou

Background of the Study

We live in a fast-changing society in which cutting-edge technological applications are pervasive in various aspects of our daily routine. In this context our knowledge and skills often become outdated. Science education is called upon to address the challenge of engendering citizens more compatible with the latest scientific advances and social demands (DeBoer 2000). In this perspective, teachers as agents of any reform need to be knowledgeable in ever-changing contexts and confront with the increasing demands at their profession (Anderson and Helms 2001). Teachers' knowledge and skills in introducing contemporary scientific topics, such as the nanoscience and nanotechnology (NST), is a crucial aspect in any initiative of integrating them in school curricula. They need to participate in professional development (PD) programs in order to update their pedagogical approaches in interpreting and transforming scientific topics which are innovative to them, in a way meaningful for their students. Considering that content-specific pedagogical content knowledge (PCK, Shulman 1987) includes teachers' knowledge on students' topic-specific understanding, the development of PCK is an important goal in a PD program (Van Driel and Berry 2012).

Nevertheless, defining the features of an effective PD program has been the subject of continuing debate in science education research literature (Loucks-Horsley et al. 2009). The scholars have reached to a consensus and highlight the benefits as teachers participate in collaborative settings (Vescio et al. 2008). The features of the supportive conditions, the collective learning and sharing of individual practice in these settings, contribute to their professional development (Vangrieken et al. 2017).

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Recently, teachers' participation in curriculum design teams has attracted major interest in educational practice as a way to comply with the aforementioned features (Voogt et al. 2011). Many scholars suggest that teachers' engagement in the process of designing and developing curriculum materials positively affects not only the curriculum implementation but their professional development as well (Coenders et al. 2010). In this respect many studies have focused, among others, on the supportive activities, the role of the facilitator and the optimal conditional factors that promote teachers' professional learning in these settings (Becuwe et al. 2016; Huizinga et al. 2015).

Nevertheless, there are only a limited number of studies that focus on the processes that supply opportunities for teachers' professional learning, as they participate in collaborative curriculum design teams (Voogt et al. 2011). Further research is needed, on issues regarding the composition of the design teams and the nature of the design task, in order to delve deeper into how these settings contribute to teachers' professional learning (Voogt et al. 2016). Within this framework, teachers' collegial interactions in collaborative settings have attracted major interest in recent studies (Horn and Little 2010; Jones et al. 2013a), as they are considered important factors that support their professional learning and improvement.

Bearing in mind the complex nature of teachers' learning, many scholars have tried to model their professional change as they are engaged in PD programs (e.g., Guskey 2002; Desimone 2009). The Interconnected Model of Professional Growth (IMPG, Clarke and Hollingsworth 2002) is an empirically founded model which conceptualizes teachers' change as a cyclic process of reciprocal interaction among various domains which encompass teacher's world. This model has attracted major interest in current research literature in the realm of teachers' education (Hamza et al. 2018; Voogt et al. 2011; Wongsopawiro et al. 2017) as it supports the identification of teacher's professional change and its representation by particular sequences of change. Given these insights, the IMPG constitutes a supportive framework in the analysis of those studying teachers' professional change.

Developing a teaching module in NST topics could be an interesting design task from an educational perspective. The NST is a contemporary scientific field that promises to have extensive implications for the entire society as it applies the unique properties of matter at the nanoscale to create new products and technologies (Roco 1999). It has attracted science education researchers' interest due to its contribution in technological and scientific literacy of future generations (Hingant and Albe 2010). Introducing the NST topics in school can be also useful for the social and ethical development of the students (Sadler 2004) since it incorporates applications that instigate discussions on their social implications (Levinson 2006). Recent studies investigate the role of Responsible Research and Innovation (RRI, Owen et al. 2012) as a framework for negotiating the social implications of the NST (Blonder et al. 2016). RRI was originally conceived as a European policy that would regulate the processes of scientific research and technological innovation in order to confine the risks of their applications and to inspire people's trust toward them. Therefore, it consists of six dimensions, i.e., engagement of all societal actors, gender equality,

science education, open access, ethics and governance (European Commission 2012).

Science education researchers have also shifted their focus on out-of-school learning settings, such as science centers and museums, in order to engage students in science teaching (Pedretti 2002). They suggest that engaging students in the process of developing a science exhibit motivates them to learn more on the related topic and to acquire new knowledge by analyzing information from various sources (D'Acquisto and Scatena 2006). As regards the NST, many efforts have been made in order to enhance the incorporation of the NST in science museums, to advance the educational programs in research centers and to develop teaching materials (Bell 2016).

Introducing the NST topics in school, negotiating aspects of RRI, and bridging formal and out-of-school learning settings constitute an educational innovation for teachers, as these approaches are novelties compared to their everyday teaching practice. Taking under consideration that any educational innovation ultimately relies on teachers, they should be considered as equal participants and active interpreters throughout the reform process (Pintó et al. 2003). Unfortunately, many scholars highlight teachers' inadequacy in teaching fundamental NST topics (Jones et al. 2008) and negotiating aspects of RRI (De Vocht et al. 2017).

Toward this end, a counter body of research has been carried out aiming to familiarize pre-college students and in-service science teachers with the NST topics (e.g., Blonder et al. 2014; Jones et al. 2013b). A review on the related empirical studies indicates that even when teachers' understanding on fundamental concepts of NST is achieved, they do not acquire the competency to effectively facilitate their students' learning in this field (Bryan et al. 2015). Wischow et al. (2013) suggest that the PD programs should not only emphasize on the content knowledge and the PCK regarding the NST but should also promote reflective practices throughout an iterative cycle of design, development, and field testing of instructional materials. Moreover, the interdisciplinary nature of the NST highlights the need to support teachers in developing instructional materials which will integrate connections of ideas among different disciplines, so as to support their students in developing integrated knowledge structures related to the NST (Stevens, Delgado and Krajcik 2010).

Aim of the Study

This study focuses on teachers' PD in NST topics, toward designing and developing a teaching module in a specialized collaborative setting. More specifically, in the framework of the IRRESISTIBLE EU-project (http://www.irresistible-project.eu), a Community of Learners (CoL, Loucks-Horsley et al. 2009) was established. Within this framework, in-service teachers collaborated with researchers and experts from different scientific disciplines in order to develop a teaching module in NST topics.

The aim of this study is to highlight teachers' interactions with colleagues in the CoL, as they confront with the emerged challenges in the process of designing and developing a teaching module in NST topics which integrates aspects of RRI and incorporates exhibits' development. More specifically, this study aims to identify the mediating processes which are induced from the aforementioned interactions and contribute on teachers' professional change. *Teacher's change* in this study is conceptualized as a process of professional learning as they are engaged in planned learning experiences (Clarke and Hollingsworth 1994). Given these insights, the research question in this study is:

> How do teachers change professionally as they design and develop a teaching module in NST topics, in the context of a CoL?

Method

The research framework in this study is a model for designing teacher education settings, the *Educational Reconstruction for Teacher Education* (ERTE, Van Dijk and Kattmann 2007, Fig. 1). Addressing the kind of thinking in terms of the model, it is necessary to study teachers' knowledge and beliefs regarding the representation of subject matter in a way that is meaningful for their students. Moreover, it is
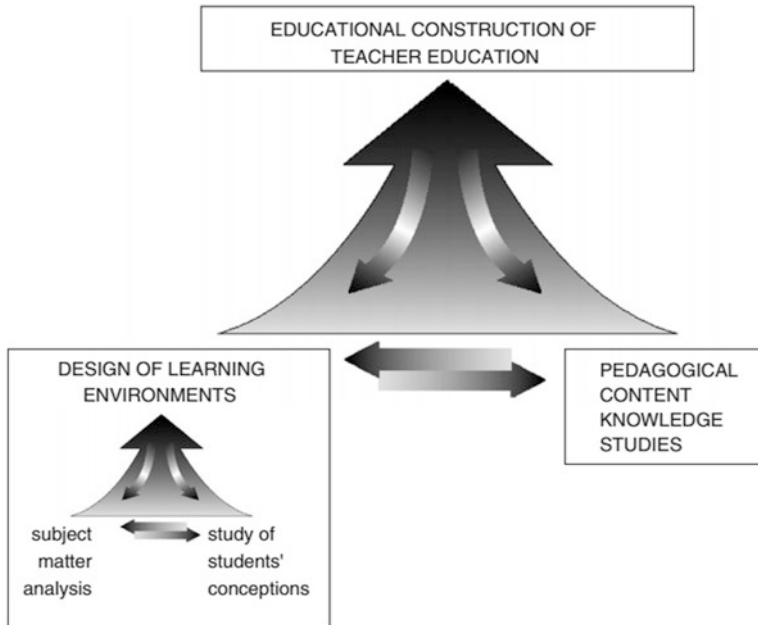

Fig. 1 The model of educational reconstruction for teacher education. (Van Dijk and Kattmann 2007)

important to study teachers' knowledge regarding students' topic-specific precon-
ceptions and difficulties along with the appropriate representations so as to over-
come these difficulties. The aforementioned studies are incorporated in the
component *pedagogical content knowledge studies* (right component shown in
Fig. 1) as teachers *design learning environments* (left component shown in Fig. 1)
for their students. In this study, teachers were challenged to bring the NST-related
issues and educationally oriented issues into balance following the principles of the
Model of Educational Reconstruction (MER) (Duit et al. 2012). MER is a frame-
work for improving teaching and learning of science which also provides a guide for
planning science instruction in school practice (incorporated in the left component
shown in Fig. 1). The educational ideas that emerge from the PCK studies can be
interpreted and reconstructed in order to develop teacher education settings, namely,
the *educational construction of teacher education* (component on the top of the
model shown in Fig. 1) and ultimately to improve teacher education. In this respect,
the new educational ideas can flow into teachers' individual knowledge and teach-
ing practice, highlighting the iterative process of the ERTE model.

Following the principles of ERTE, we conducted a recursive elaboration on the
components of this model, as shown in Fig. 2.

More specifically, a review on the research literature regarding the empirical
studies on teacher education was the starting point in order to develop the CoL as a
context for teachers' PD (arrow 1 shown in Fig. 2). The next step was to engage
teachers in the process of analyzing and clarifying NST topics considering students'
perspectives in order to design and develop a teaching module (arrow 2 shown in
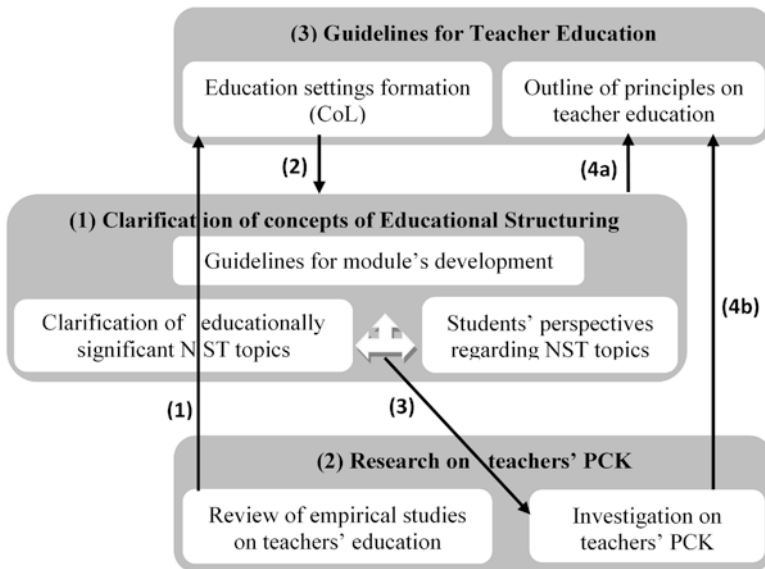Fig. 2, for further detail see Stavrou et al. 2018). The recursive process of developing

Fig. 2 The recursive process of ERTE as it was conducted in this study

the module in conjunction with the study of aspects of teachers' PCK (arrow 3 shown in Fig. 2), supplied valuable feedback (arrows 4a, 4b shown in Fig. 2) in order to reflect on the features of the CoL and the processes therein that facilitate teachers' professional change.

The CoL in this study consisted of members with different credentials and diverse expertise aiming to supply teachers with qualified feedback considering their task. More specifically the members of this group were:

- *Five in-service teachers* (two chemistry teachers, two physics teachers, and one teacher of primary education) with teaching experience ranged from 12 to 28 years. All of them were highly qualified individuals since four of them had a PhD in science education and one of them a PhD in chemistry. Teachers participated in this study voluntarily, and the conduction of the research had been approved by the National Institute of Educational Policy.
- *Four science education researchers.*
- *Two researchers from the field of NST* with expertise in the recent advancements in this field.
- *Three experts in science communication.*

The shared task among the CoL members was to design and to develop an inquiry-based teaching module in NST topics that incorporates aspects of RRI and out-of-school learning environments (i.e., science centers and science museums). The final deliverable after implementation was the development of science exhibits by the students.

Research Design

The process of design, implementation, and evaluation of the module was 1-year long in a period of time and was divided into three interrelated phases, as shown in Fig. 3.

Since the members of the CoL were located in different districts of Greece, ten virtual meetings and three workshops were conducted in order to facilitate the collaboration and the exchange of ideas and materials among the CoL members.

In more detail:

1. *In Phase A* (Plan & Prepare), a series of six virtual meetings were carried out. In each meeting the CoL members were familiarized with an aspect regarding the module's development. More specifically, the topics discussed during the virtual
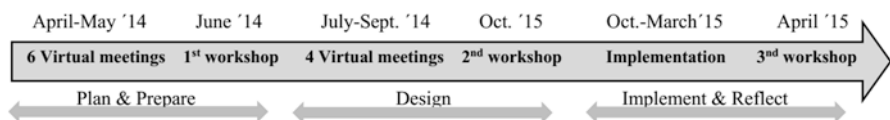

Fig. 3 The different phases and the timeline of the PD program in this study

meetings were (i) NST as a science content, (ii) research in science education regarding the teaching and learning of the NST, (iii) inquiry-based learning in science education, (iv) aspects of RRI, (v) principles for developing science exhibits, and (vi) integration of WEB 2.0 tools in science teaching. Each topic was introduced by the attendant expert which had developed and distributed before the meetings a specially developed document, highlighting the main aspects of the topic under inspection. In a following 3-day workshop, the CoL members participated in guided visits in science laboratories and science museums. They were familiarized with nano-products and related applications along with interactive science exhibits. Furthermore, they had the opportunity to interact with exemplary teaching materials, according to the latest literature review, which have been used in teaching and learning of the NST topics.

2. *In Phase B* (Design), teachers' proposed guidelines for the module's design were the subject under inspection in a new round of four virtual meetings. The CoL members had the chance to contribute in group discussions, to swap ideas and to reflect on the proposals of their colleagues. Subsequently, the teachers presented their teaching modules in a new 2-day workshop, and the teaching module was finalized as an outcome of intense interactions and constructive collaboration among the CoL members.

The module (which is briefly presented in Table 1) consisted of seven 90-minutes lessons oriented toward the 5E instructional model of inquiry-based science education (Bybee et al. 2006). Nevertheless, apart from the 5E stages of Bybee (i.e., engagement, exploration, explanation, elaboration, and evaluation), the module was enhanced with an additional stage of exchange, in which students were challenged to communicate the acquired knowledge by designing and developing a science exhibit. Elaborating further on the content of the module's structure (for more detail see Stavrou et al. 2018), students' engagement in NST topics (lessons 1 and 2) took place through videos which present current applications related to the NST and through a visit in a science museum in order to interact with NST-related exhibits. During lessons 3 and 4, students were engaged in hands-on activities, e.g., measuring

Table 1 Main structure of the module

Engage	*Lesson 1*	Introduction
	Lesson 2	Visiting the science museum
Explore and explain	*Lessons 3 and 4*	Nanoscience applications: self-cleaning materials
		How small is nano?
		Size-dependent properties
Elaborate	*Lesson 5*	RRI issues:
		Newspaper articles
	Lesson 6	Visiting the research center
		Discussion with experts on NST and RRI issues
Exchange and evaluate	*Lesson 7*	Construction of exhibits

the dimensions of everyday objects in nanometers and using surface area-to-volume ratio in order to interpret the properties of hydrophobic nanomaterials and the change of nanogold colloids' optical properties. In the following two lessons (5 and 6), students were engaged in discussions concerning ethical aspects of the NST such as safety, toxicity, or difficulty of nanomaterials' disposal and governance and ethical issues in science, e.g., transparency of scientific research and funding. In the final lesson, students were engaged in the process of designing and developing interactive exhibits in order to communicate their knowledge and major concerns, as regards the applications of the NST.

3. *In Phase C* (Implement & Reflect), the module was appropriately adjusted and implemented by the five teachers in their classes, i.e., in a primary school class (aged 11–12), in two lower secondary classes (aged 14–15), and in two upper secondary classes (aged 16–17). In a final 2-day workshop, teachers shared their experiences from students' reflections during module's implementation. This process triggered the negotiation of the team on finalizing the teaching module.

Data Collection

Video recordings of the CoL meetings (three workshops and ten virtual meetings) and semi-constructed interviews with teachers after the second workshop (prior the implementation phase) were used for data collection. The interviews focused on teachers' views regarding the specific features of the CoL (i.e., composition of the team, interactions with colleagues, material and information supplied) that primarily supported them in order to accomplish their task.

Data Analysis

Data analysis started with the transcription of the video recordings of the CoL meetings and teachers' interviews which comprised 40 h of audiovisual data.

The next step was to utilize the IMPG in order to analyze the transcribed data from the video recordings so as to record teachers' professional change in this context. According to the authors of this model (Clarke and Hollingsworth 2002), teachers' change can begin at any point of this process via belief, practice or change in students' outcomes. This model conceptualizes teachers' professional change as a cyclic process of reciprocal interaction among the External Domain (source of information, stimulus or support), the Personal Domain (teachers' knowledge, beliefs and attitudes), Domain of Practice (professional experimentation) and Domain of Consequence (salient outcomes), through the mediating processes of *reflection* and *enactment*. Enactment denotes the translation of a belief or a

pedagogical model into action, while reflection denotes an active and careful consideration of teachers, in something previously encountered.

The IMPG was adapted in this study for the analysis of the transcribed data, as shown in Fig. 4 (numbers on the arrows indicate the correlations among the domains).

More specifically, External Domain in this study consists of the CoL members, while Personal Domain comprises teachers' knowledge, beliefs, and personal perspectives. According to the authors of the IMTPG, the Domain of Practice includes all forms of professional experimentation since teachers' professional practice is not ended in classroom teaching. This is significant in this study, since it focuses on teachers' professional change in the process of designing and developing a teaching module and not on direct and specific change in classroom practice. Domain of Consequence comprises teachers' considerations on students' perspectives during the module's development or toward their reflections after the module's implementation. Reasonably, teachers' professional change is cultivated throughout the affordances and constraints offered by the Change Environment which in this study was the context of the CoL. In our analysis the term enactment has been broadened in terms of teacher's contribution with distinct ideas and proposals during the discussions of the team regarding the module's design and development. Respectively, reflection is conceived as teachers' process to look back on their intentions or practice regarding the module's development and make it the object of purposeful critical thinking. Given the power of the IMPG as an interrogatory tool, criteria were established in order to register the correlations among the district domains of the model, as they emerged from the transcribed data. Indicatively, examples of the criteria which have been used in order to establish the correlations among the domains are given in Table 2.

Fig. 4 The operationalization of the interconnected model of professional growth in this study
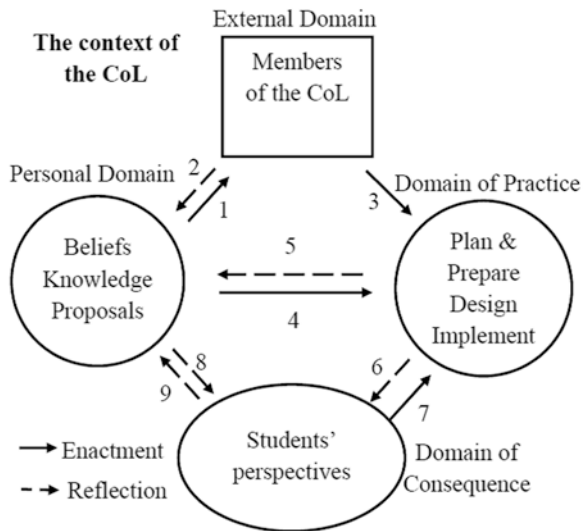
Table 2 Criteria used to establish correlations among the domains of the IMPG

Correlation	Criterion	Example
PD to DP (arrow 4, Fig. 4)	Teacher shares a belief/concern or pose an idea/ suggestion powered by his/her knowledge/experience regarding module's detailed development	I think it would be interesting to start with a video presenting impressive nano applications and then to show them real nanomaterials and to ask them: Would you use these materials?
ED to PD (arrow 2, Fig. 4)	Teacher reflects on external information or stimuli regarding the topic under inspection	What I am thinking, considering what [name of an expert] have just said, is that our students will change their attitudes toward visiting science museums hereinafter. They will value museums differently.

Note: PD → Personal Domain, ED → External Domain, DP → Domain of Practice

Table 3 Categorization of the topics under inspection on teachers' interactions with colleagues in the CoL

Emerged codes	Criterion
Strategies for specific science topics (teaching material)	Issues regarding the supply, the adaptation, the conceptual power, or the evaluation of simulations, models, activities, or experiments
Science-specific strategies (inquiry and out-of-school learning features)	Issues regarding the implementation of inquiry and the integration of out-of-school learning features in the module
Science content (NST/RRI)	Issues regarding the clarification and the elaboration of concepts regarding NST and RRI
Exhibits	Issues regarding exhibit development

The next step was to develop pictorial representations of the IMPG for every teacher and for each phase of the professional development program. The emerged representations were primarily studied for each teacher individually in conjunction with the study of the transcribed interview. Subsequently, a comparative analysis among teachers' pictorial representations of the IMPG was conducted in order to identify the overarching features of the emerged correlations.

Since we were interested on how teachers' interactions supply opportunities for their professional learning, there were quantitative estimates of the frequency in which teachers purposefully interact with other teachers or experts (namely, researchers in NST, researchers in science education, and experts in science communication) in the CoL, on issues regarding the emerged challenges in the process of the module's development.

Concurrently, we registered and analyzed the topics under inspection during their collegial interactions, as shown in Table 3. Given the shared task of developing a teaching module, teachers' collegial discussions focused on issues regarding the different aspects of the module (e.g., NST, RRI, science exhibits) and the way that they can be educationally reconstructed following the principles of MER. In this respect, these topics unveil teachers' effort to interpret and transform the acquired

knowledge, in a module that will facilitate their students' understanding. Considering this perspective, the aforementioned topics are correlated with aspects of the PCK.

In this study the process of data coding was oriented toward the aspects of PCK as they have been conceived by Magnusson et al. (1999). More specifically the component *Strategies for specific science topics* comprises issues regarding the activities, the experiments, the simulations, and models considering NST instruction, namely, the teaching material (as shown in Table 3). Respectively, the component *Science-specific strategies* in Magnusson's model comprises issues regarding the development of an inquiry-based module along with issues considering the integration of out-of-school learning features. Issues regarding teachers' familiarization with the NST topics and the aspects of RRI constitute the prerequisite knowledge base (component *Science content* in Table 3) for teachers in order to develop the teaching module. Finally, issues regarding teachers' perspectives as regards the development of science *Exhibits* were registered as a distinct code, considering that exhibits are an integral part of the implementation process.

Results

Teachers' Interactions with Colleagues in the CoL

The dynamic of teachers' interactions with colleagues in the CoL toward the different phases of the module's design and development is shown in Fig. 5. The findings indicate that in *Phase A* (Plan & Prepare), teachers address their personal
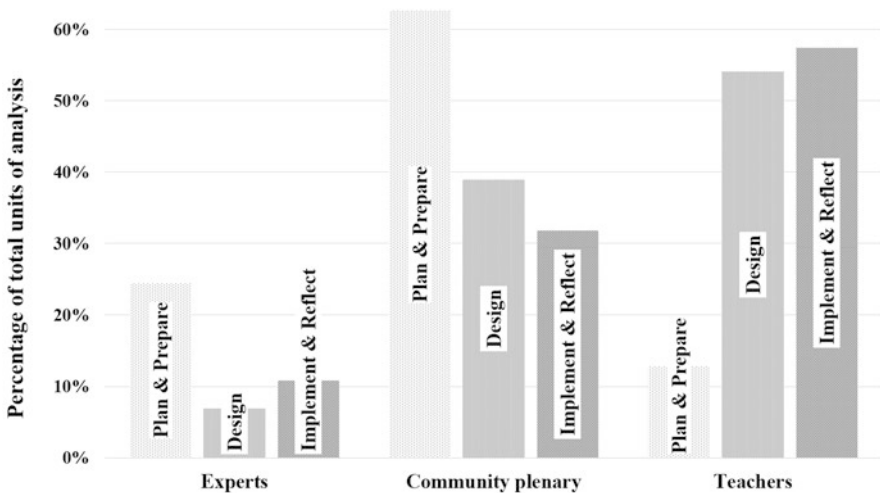

Fig. 5 Teachers' interactions with colleagues in the CoL toward the different phases of the module's development

perspectives considering the module's design to the plenary of the CoL. It is noteworthy that the scores of this component possess comparatively high values as the process of the module's detailed development and implementation proceeds. It seems that considering teachers as professionals and equal members in a team with qualified colleagues, i.e., researchers and experts from different disciplines, motivates them to share their teaching practice and to address their new educational ideas to the plenary of the CoL. In *Phase B* (Design), teachers' interest for interaction progressively shifts to the teachers of the team, as they anticipate feedback, regarding the module's detailed development from colleagues which they consider *experts* of the classroom context.

In *Phase C* (Implement & Reflect), this component in teachers' interactions sustains notably high scores as they anticipate teachers' reflections on the implementation process in order to validate their personal perspectives regarding the accomplished task.

Teachers–experts interactions are mainly upgraded in *Phase A* (Plan & Prepare) given that the teachers in this phase are interested on analyzing and clarifying aspects of the module, e.g., NST and RRI, which are innovative to them. As the process of the module's development proceeds in *Phase B* (Design), these interactions are restricted on issues regarding the balanced integration of these aspects in the module. In the *Phase C* (Implement & Reflect), teachers–experts interactions are primarily focused on issues regarding the development of the exhibits.

Topics Under Inspections During Teachers' Collegial Interactions in the CoL

The frequency in which specific issues regarding the module's development attract teachers' interest, during their interactions with colleagues, is portrayed in Fig. 6.

In detail, during *Phase A* (Plan & Prepare), teachers focus their interest mainly on the supply of the exemplary teaching material (component Strategies for specific science topics shown in Fig. 6). In *Phase B* (Develop), they shift their interest on the proper modification and adaptation of the available teaching material considering students' perspectives and the context of implementation, i.e., their grade. In *Phase C* (Implement & Reflect), teachers' concerns focus on evaluating the teaching material in terms of engaging their students in the module and facilitating their understanding in the NST topics.

Secondarily, but not of minor importance, is teachers' concerns on embodying aspects of an inquiry method (component Science-specific strategies shown in Fig. 6) in a module that integrates features which are innovative to them from an educational perspective. Incorporating out-of-school settings in a module which integrates NST topics and issues related to risk assessment and ethics of NST's applications seems a challenging process even for experienced in-service teachers.
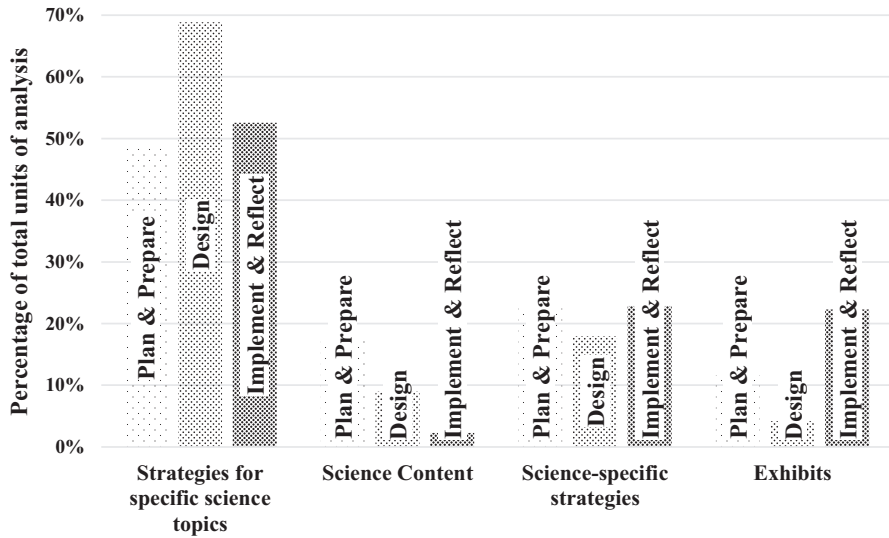
Fig. 6 Aspects of PCK that attracted teachers' interest and major concerns during their collegial interactions in the CoL

Teachers' interest in broadening their knowledge base regarding the science content of the NST and the aspects of RRI (component Science Content shown in Fig. 6) is primarily upgraded in *Phase A*, while issues regarding the development of science exhibits attract their interest mainly in *Phase C*.

Discussion

In this section we discuss the main research question of this study which is: *How do teachers change professionally as they design and develop a teaching module in NST topics, in the context of a CoL?* The abovementioned findings supply insights which support the descriptive elaboration of the mediating processes which develop the sequences of teachers' professional change in this context, in terms of the IMPG. More specifically:

In *Phase A* (Plan & Prepare), teachers enact the information and stimulus received from the external domain (arrow 1 shown in Fig. 4) during the first round of the virtual meetings by interacting primarily with the experts in the CoL. During the first workshop, they contribute in group discussions by reflecting primarily on issues regarding the analysis and the clarification of the exemplary teaching material (arrow 2 shown in Fig. 4). Concurrently, they address their educational ideas regarding the module's design to the plenary of the CoL considering students' perspectives (arrow 8 shown in Fig. 4).

In *Phase B* (Design), teachers enact the acquired knowledge and their informed pedagogical approaches in their teaching practice (arrow 4 shown in Fig. 4), as they structure in detail their teaching module. Their interactions mainly with peer teachers in the CoL supply them with valuable feedback regarding their educational approaches and supply them with the opportunity to experience the practical alternatives of their colleagues. The abovementioned interactions trigger multiple reflection processes that challenge their personal intentions and impact their initial perspectives (arrow 5 and arrow 2, respectively, shown in Fig. 4), as regards the process of developing a teaching module that effectively supports their students' understanding in NST topics (arrow 8 shown in Fig. 4).

In *Phase C* (Implement & Reflect), teachers enact their refined ideas and personal perspectives during the process of properly adjusting the shared structure of the module, in order to implement it in school (arrow 4 shown in Fig. 4). The implementation process supplied them with valuable feedback on students' perspectives as regards the prevailing features of the module which effectively engaged them in the implementation process and facilitated their understanding (arrow 6 shown in Fig. 4). Interacting with peer teachers on the related experiences regarding the module's implementation process, trigger multiple reflection processes which stimulate them in validating their personal perspectives (arrow 2 shown in Fig. 4) regarding the accomplished task and end up in the process of finalizing the module.

Conclusions

This study unearths teachers' interactions with their colleagues in the context of a CoL as they design and develop a teaching module in NST topics. The findings indicate that as they confront to the challenges of a task that constitutes an educational innovation for them, they progressively shift their interest for interaction among the qualified members of the CoL, as they anticipate feedback on their personal interests and major concerns in each phase of the module's development. During these interactions teachers are engaged in activities and processes that support their professional learning.

More specifically, in the context of the CoL they are engaged in reflection processes considering the teaching experiences and the practical alternatives of the peer teachers. Concurrently, they have the opportunity to clarify issues that are innovative to them, i.e., contemporary scientific topics and research-based approaches for its educational reconstruction, with researchers in NST and in science education. These interactions upscaled their skills in order to introduce contemporary scientific topics in class, given that the shared structure of the module documents a balanced integration of the different aspects, e.g., formal inquiry-based activities and experiments with out-of-school settings features. Given these insights, the findings in this study suggest that such interactions are promising in order to reform experienced teachers' practical knowledge with regard to implement an educational innovation in their classrooms, confirming the findings of Van Driel et al. (2001).

Furthermore the findings in this study highlight teachers' collegial interactions on issues regarding the teaching material used for NST instruction. Indicatively, teachers reflect on their personal orientations in utilizing the available resources and share the rationale on its educational integration in the module, i.e., by providing collegial feedback (in *Phase B*) and its evaluation considering students' reactions after implementation (in *Phase C*). These interactions triggered stimulating dialogues that inspired them to synthesize new educational ideas regarding the interpretation and the transformation of cutting-edge science topics in a way meaningful to their students. The abovementioned interactions offered opportunities that cultivate aspects of their curriculum design expertise (Richey et al. 2001), confirming recent findings in contemporary research literature (Huizinga et al. 2015; Voogt et al. 2016).

A key contribution of this study is that it unearths the mediating processes, as they are induced by teachers' interactions in the CoL, which develop the sequences of their professional change, in terms of the IMPG, in the context of a curriculum design team. It is noteworthy that *reflection* is indicated as the mediating process that raises major impact on teachers' personal perspectives regarding the development of innovative teaching material (Personal Domain of the IMPG). *Enactment* is primarily a process that supports them in reforming their teaching practice, in terms of the design task, by integrating the acquired knowledge and research-based pedagogical approaches in the teaching module. In this respect, this study identifies the mechanisms that contribute to teachers' professional learning as they design and develop innovative curriculum material in the context of the CoL.

Given these insights, this study contributes in the existed knowledge regarding teachers' professional learning in cutting-edge science topics, in conjunction with the literature regarding the development of their expertise in collaborative curriculum material design. It contributes in empirical research literature regarding teachers' professional development to implement educational innovations in school.

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Developing Pre-service Teachers' Competencies of the Management of Students' Allergies in the School Environment

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Introduction

Allergies are increasingly recognised as a serious, global public health concern. They are one of the most common chronic paediatric diseases, placing a significant burden on the health system and contributing substantially to the impaired quality of life and to school absences. The most severe systemic allergic reaction that requires immediate management is anaphylaxis. The most common causes of anaphylaxis in children are food and insect stings (bees, wasps). Recent developments in the general public's understanding of health issues have increased the need for developing teachers' adequate medical competencies. Evidence suggests that the majority of anaphylaxis occurs outside health institutions and, consequently, parents, pre-school and school employees (especially teachers), and children must be well educated about what anaphylaxis is and how it should be treated before medical personnel arrive at the scene. However, far too little attention has been given to adequately inform these stakeholders about how to manage children's severe allergic reactions in the school environment. Another significant point in understanding the teachers' role in managing medical issues in pre-schools and schools is the fact that legislation is lacking in this field.

The major objective of this chapter was to present Slovene pre-service teachers' competencies about managing allergic reactions. The important aim is also to show

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the effects of a short educational programme in allergy management that can be implemented to develop these competencies before pre-service teachers enter their profession. However, this chapter does not present the development of teachers' competencies to teach science in schools, but it illustrates the importance of teachers' specific medical knowledge to function as competent caregivers to allergic children in school environment. This context can be framed as a science education for pre-service teachers at university level.

Teachers' Competencies

Eurydice[1] attempted to establish some parameters in distinguishing between knowledge and competencies that individuals should develop during their education (Key Competencies 2002).

Lundvall and Johnson (1994) determined four types of knowledge important to the knowledge-based economy: 'know-what' (factual, codifiable knowledge that can be transferable), 'know-why' (scientific understanding and the impact of science on humanity), 'know-how' (the capability of performing certain tasks), and 'know-who' (knowing which people possess the necessary know-what, know-why, and know-how).

Due to the decreasing need to remember facts (declarative knowledge) and the simultaneously constantly increasing amount of this information, the growing need for mastering instruments/tools/procedures through which we can select the correct process and use information is a reality. The concept of competence is being applied to this kind of knowledge, combining the above-presented types of knowledge. In education, *key competencie*s are essential, and Eurydice (Key Competencies 2002) reports that 'the majority of experts seem to agree that for a competence to deserve attributes such as "key", "core", "essential", or "basic", it must be necessary and beneficial to any individual and to society as a whole'. The report also stresses the importance of someone to be able to:

> Successfully integrate into a number of social networks while remaining independent and personally effective in familiar as well as new and unpredictable settings. Finally, since all settings are subject to change, a key competencies must enable people to constantly update their knowledge and skills in order to keep abreast of fresh developments. (Key Competencies 2002).

Following these assumptions, the importance of competencies to the teacher is even greater, because teachers can influence students' well-being and development (conative and cognitive) in the school environment. However, teachers' competencies can be defined as general (those that are obtained by general pre-service teacher education, these competencies are transferable to different fields of teachers' actions

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[1] Eurydice is a network that supports and facilitates European cooperation in the field of lifelong learning by providing information on education systems and policies in 38 countries and by producing studies on issues common to European education systems.

in the school environment, e.g. communication abilities, teamwork, developing personal knowledge, and lifelong learning, comprising personal and interpersonal aspects) and specific (those that are developed by specific courses in pre-service teacher education; teachers can use them to teach specific subjects). Razdevšek Pučko (2005) summarised a Eurydice study, identifying 'new teachers' competencies, which are (1) teaching by using up-to-date information-communication technology, (2) special needs students' integration, (3) teaching in multicultural environments, (4) school management and administrative work, and (5) conflict management. It can be concluded that competence includes the knowledge, skills, and attitudes required for performing tasks in a particular profession, and the person has acquired them with formal and continuous professional education, at work or elsewhere (Može 2005). It is also important to emphasise that, since competencies are observable, they can also be measured. It is possible to assess teacher's competency for working in the teaching profession by observing his/her work and by his/her performance or by teachers' self-reporting their views on the competencies needed for successful teaching.

Teachers' Medical Competencies and Students' Allergies

Following the general teachers' competencies addressed above, a broader view of teaching profession can be identified. Taking into account integrating different special needs students into the school environment, the need for teachers' additional competencies emerges. The competencies discussed in this chapter refer to teachers' different medical knowledge and skills as well as attitudes towards these topics. Allergic reactions in children are a serious health issue in kindergarten and school settings (Muraro et al. 2010; Muraro et al. 2014a, b, c). They can manifest in multiple ways, including life-threatening anaphylaxis (Grabenhenrich et al. 2016). Anaphylaxis can be described as a rapidly developing severe, life-threatening systemic allergic reaction, in which the immune system responds to otherwise harmless substances and can result in death. The most common causes of anaphylaxis in children include food, insect stings (bees, wasps), and medicines. The reaction may begin within minutes of exposure and can rapidly progress to cause airway constriction, skin and intestinal symptoms, and altered heart rhythms. The skin is involved in 80% of anaphylactic incidents in the form of itching, skin rash, and generalised redness or swelling under the skin's surface (angioedema). In other cases, the respiratory system may be involved, in the form of irritation and inflammation inside the nose (acute rhinitis) or asthma; the digestive tract (nausea, vomiting, stomach cramps, or diarrhoea) or the cardiovascular system (palpitations, increased heart rate, or low blood pressure) may be involved. These may lead to dizziness, loss of consciousness, and in the worst scenario, to respiratory or cardiac arrest. The only way to avoid an allergic reaction due to food is to avoid the foods that cause the reaction. For anaphylaxis, the administration of intramuscular adrenaline is the first-line treatment (Muraro et al. 2014a, b, c).

Food allergies are common among school children, with an estimated overall prevalence of 4–7% (Muraro et al. 2010). Up to 18% of children with food allergies experience various allergic reactions to food, including anaphylaxis, in the school environment (Eigenmann and Zamora 2002; Mehl et al. 2005; Grabenhenrich et al. 2016). Medical records show that 61% of English schools have at least one child at risk of anaphylaxis (Bohlke et al. 2004). At the same time, several studies (Bansal et al. 2005; Ercan et al. 2012; Polloni et al. 2013; Kilger et al. 2015; Hogue et al. 2016; Polloni et al. 2016), including the EUROPREVALL study (Le et al. 2014), have identified a low level of teachers' knowledge and skills for managing children at risk of anaphylaxis in schools. More specifically, in the EUROPREVALL project, which included 190 schools in 8 countries, students' food allergies were recognised in 23% of schools, food labels were read in 17% of schools, and 26% of schools had adrenaline auto-injectors, but only 53% of school employees knew how to administer them, and only 11% of them used them when indicated (Le et al. 2014). Mahl et al. (2005) concluded that only 12% of teachers can correctly apply epinephrine auto-injector and that 75% of children with anaphylaxis do not receive adequate first aid.

The importance of the knowledge of school personnel in preventing and recognising children's allergic reactions and providing first aid is pointed out in recommendations of the European Academy of Allergology and Clinical Immunology (EAACI) (Muraro et al. 2014a, b, c) and others, such as guidelines recommended by the Australasian Society of Clinical Immunology and Allergy (ASCIA) (Vale et al. 2015) and guidelines for the USA (Sheetz et al. 2004). Similar guidelines were also presented by Polloni et al. (2013). Guidelines also emphasise the importance of the continuous education of in-service teachers' and other school personnel (principals, administrative support personnel, cooks, etc.) in managing students' potential severe allergic reactions in the school environment. However, attempts to implement effective educational models to improve teachers' medical competencies regarding providing first aid to students with severe allergic reactions are rare (Muraro et al. 2010; Muraro et al. 2014a, b, c). It can be summarised (Litarowsky et al. 2004; Patel et al. 2006; Luu et al. 2012; Wahl et al. 2015; Lanser et al. 2016) that educational programmes in managing children's allergic reactions improve parents' and kindergarten or school employees' knowledge and skills about allergy and adrenaline auto-injector application, but there is a lack of reports on the long-term effects of education (Muraro et al. 2014a, b, c) and scarce data on how often these educational programmes must be repeated to secure adequate teachers' medical competencies. It is important to emphasise that even short training courses in allergy and anaphylaxis management for school personnel significantly improve participants' knowledge about this topic (Polloni et al. 2013), but there are insufficient data about the persistence of this knowledge after a longer time.

Another issue, but one that has received very little attention, when providing care for a child with an allergy might be that they are dealing with bullying (Lieberman et al. 2010; Shemesh et al. 2013; Muraro et al. 2014a, b, c), reduced quality of life (Avery et al. 2003), and impaired school performance (Muraro et al. 2010).

Lieberman et al. (2010) were the first to explore bullying among food-allergic paediatric patients, finding that 86% reported bullying. Further studies (Shemesh et al. 2013) showed that 45.4% of children and 36.3% of parents reported bullying and that food-allergic students have approximately two times higher probability of being bullied in verbal, relational, social, or physical ways than their nonallergic peers (Muraro et al. 2014a, b, c). Bullying has significant negative consequences on victims, including psychosomatic complaints and academic, emotional, and behavioural problems (Reijntjes et al. 2010; Ttofi et al. 2011; Gini and Pozzoli 2013). However, educational programmes, to develop teachers' competencies to observe, cope, and prevent bullying a child with an allergy by their peers, are still lacking.

Allergic Student in Kindergarten and in School: Slovenian Context

In Slovenia, courses in allergy management are provided for parents and kindergarten/school personnel (Šoster Križnik et al. 2015) and also for pre-service teachers (Posega Devetak et al. 2016a, b). The preliminary results are promising, with participants reporting enhanced theoretical ability, a willingness to undertake the appropriate first-line management of anaphylaxis in children, and a sense of being able to do so. To put the need for implementing adequate educational models for teachers and pre-service teachers (while they are educated at university to become teachers) into perspective, it should be pointed out that in Slovenia in recent years, adrenaline auto-injectors (AAI) have been prescribed for 260–350 children per year, with 120–150 being prescribed for the first time (Vesel et al. 2015). There are currently no nurses employed in kindergartens or schools in Slovenia. There are 850 kindergartens, 450 primary, and 180 secondary schools in Slovenia. However, according to a comprehensive school health education programme, Preventive Health Programmes for Children and Adolescents, developed by The National Institute of Public Health (NIJZ), registered nurses employed by local health institutions can be important stakeholders and providers of various health educational programmes when they are invited to the school (Pucelj et al. 2016). Legislation on the issue of food allergies and anaphylaxis is rarely present in different countries with the exception being some countries with fatalities due to anaphylaxis, e.g. in Canada defined in Sabrina's Law from 2005 or in England's guidance on the use of adrenaline auto-injectors in schools from 2017 available at https://www.gov.uk/government/publications/using-emergency-adrenaline-auto-injectors-in-schools.

Currently, as in the majority of countries, there is no law that regulates what is expected from the teachers in Slovenia regarding this issue, although (1) parents and public and medical personnel expect teachers to be able to prevent and manage student's allergic reactions, and (2) studies suggest that school boards in legislated environments can make greater efforts to support students at risk for anaphylaxis in comparison to non-legislated environments (Cicutto et al. 2012).

Pre-service Teachers Understanding of Allergic Child Management in Schools

Pre-service teachers are essential stakeholders for successful education outcomes regarding developing competencies for managing allergic children before they become in-service teachers. According to the available literature, one major study has been done on the knowledge and attitudes of pre-service teachers regarding managing allergic children in the school environment (Devetak et al. 2018). Results indicated problems that pre-service teachers in Slovenia have about managing students' allergic reactions in school. Following the conclusion of this study, the educational programme on allergic reactions was developed for all pre-service teachers engaged into the master programme at the University of Ljubljana, Faculty of Education, Slovenia. It is important to emphasise that the education on allergic reactions is currently routinely available only to pre-service home economics teachers, who will also be responsible for planning and providing food for children in schools (Posega Devetak et al. 2016a, b).

The purpose of the cross-sectional, descriptive study (Devetak et al. 2018) was to explore the current understanding of allergic child management among pre-service teachers in Slovenia. The aim was also to understand the impact of different factors (i.e. gender, study programme, participation in an allergy education programme, and attitude towards child health topics) on pre-service teachers' knowledge and allergy management competencies. However, some specific conclusions are summarised here, and, to aid in understanding the results, some research framework considering the participants, instrument, and research design is presented below.

In the context of this study, 572 pre-service teachers participated; 319 (56%) of the participants were enrolled in the first year and 253 (44%) in the fourth year. Seven per cent of participants are male and 93% female. They were on average 21.5 years old ($SD = 2.7$ years). All participants were undergraduate pre-service teachers enrolled in the study programmes in the 2014/2015 academic year at the Faculty of Education, University of Ljubljana; 41.8% of the participants were enrolled in undergraduate programmes with some science background (i.e. two-subject pre-service teachers of biology, chemistry, physics, and home economics, as well as pre-service primary school teachers whose programme includes some basic biology, chemistry, and physics). The others (58.2%) had no science courses. A total of 15.6% of the participants were studying to become pre-school teachers (group 1); 21.9% to become subject teachers (group 2); 33% to become social pedagogy, special education, or art teachers (group 3); and 29.5% to become primary school teachers (group 4). According to their reports, 27.8% of the participants had allergies.

The Teachers' Health Competencies Development-Allergy Questionnaire (THCDAQ) was applied in the sample; it was developed specifically for this study. Some items were based on a questionnaire used by Polloni et al. (2013) and adapted to the Slovenian context. The questionnaire was developed by a multidisciplinary team of experts from the field of paediatric allergology and science education. The final version comprised a total of 34 multiple-choice and open-ended items, divided

into 4 groups: (1) 6 items about participants' general information; (2) 11 Attitude items on Child Health issues (AMCH); (3) 10 knowledge items on Managing Children's Allergic Disease (MCAD), including the prevention, recognition, and management of anaphylaxis, asthma, and food allergies (participants could achieve from one to ten points by solving items in the MCAD part of the instrument); and (4) 7 items that measure pre-service teachers' Self-Perceived Allergy Management Competencies (SPAMC).

The results show that pre-service students' understanding of managing child's allergic diseases was average (M = 59.4%; SD = 16.1% success). The highest achievement scores were on prevention of food allergies and asthma management (80%) and the lower on anaphylaxis identification (48.3%) and management of anaphylaxis. Sixty-three per cent of pre-service teachers would choose correct position, less than a half (41.3%) correct order of actions during anaphylaxis, less than one quarter (23.8%) knew adrenaline was the most important drug for anaphylaxis, and only 4.9% would know how to use an auto-injector. The highest average knowledge on the management of child's allergy and anaphylaxis was identified in the subject teacher's group (M = 63.3%, SD = 15.5%) and the lowest average knowledge level in the group of social pedagogy, special education, or art teachers (M = 55.6%, SD = 16.4%). The differences were significant: $F(3,568)$ = 6.4, p = ≤0.0001. There was no significant difference regarding the duration of education, science background, or self-allergy reports in pre-service teachers' knowledge about managing students' allergic reactions. 98.9% of pre-service teachers were aware that understanding allergy concepts was important. Eighty-five per cent of them showed positive attitudes towards learning more about different children's health issues, and only 17.1% of pre-service teachers think that they are not responsible for students' health in the classroom. 34.3% of the pre-service teachers expressed that they have not received any information, and only 5.4% of the pre-service teachers do not see the importance of additional education. The differences in MCAD score between pre-service teacher groups presented above (aware/not aware of importance of medical competencies, positive attitude/not positive attitude for medical education, responsible/not responsible for students' well-being, received/not received information on health issues, important/not important medical education) were not significant, except the statistically significant score on MCAD between students who expressed high or low interest for developing adequate medical competencies (t = −3.15 (df = 570); p = 0.002).

The conclusions of this study indicate that the duration of education, science background, or having an allergy had no impact on the knowledge of how to manage children with allergies among pre-service teachers. As expected, pre-service teachers' understanding of managing children's allergic reactions was average, as education on allergic reactions is currently only routinely available to a small group of pre-service home economics teachers at the Faculty of Education in Ljubljana. The low level of pre-service teachers' knowledge seemed comparable to the results of Lanser et al. (2016), or even lower than, the level determined in certain previous studies involving in-service teachers (Polloni et al. 2013; Polloni et al. 2016). A subgroup of pre-service teachers who received 2 h of basic allergy training

maintained higher knowledge about allergy management, even after 26 months (a longer time than the described interventions in some other published European studies (Patel et al. 2006). Even though pre-service teachers are familiar with adrenalin auto-injectors, they do not feel competent to use them. The results emphasise the need for specific educational interventions and improvements in school health policies to support schools to deal with allergic students, thus ensuring their safety and psychological well-being.

Practical topics such as the side effects of adrenaline and its intramuscular application should, therefore, be specifically addressed, as such issues might represent important obstacles to caregivers for administering adrenaline to a child in need. Furthermore, as already recommended by the EAACI (Muraro et al. 2014a, b, c), a broader coordinated national and EU strategy, including such areas as defining legal aspects (as also pointed out by our participants), should be developed. The introduction of a well-defined law on the management of anaphylaxis is an important and necessary step, as demonstrated elsewhere (Cicutto et al. 2006).

It is essential to emphasise that developing an efficient, effective educational programme for teachers regarding anaphylaxis, which could also be repeated by other tutors and therefore broadly disseminated across Slovenia, should also be important from the point of view of public health. This is especially necessary because the wider availability of adrenaline auto-injectors in primary schools has been recently authorised by paediatricians and the National Institute of Public Health in Slovenia (Veninšek Perpar et al. 2018). Therefore, the adequate development of pre-service teachers' and teachers' competencies for managing children's severe allergic reactions is needed.

Pre-service Teachers' Competencies Developed by the Implementation of the Educational Programme: The Evaluation Study

The conclusions presented by Devetak et al. (2018) were the basis for developing the educational programme for pre-service teachers to stimulate the development of medical competencies of pre-service teachers at the beginning of their 1-year master programme at the Faculty of Education, University of Ljubljana.

The main purpose of this evaluation pre-post design study was to analyse how a short theoretical and practical intervention programme could influence the pre-service teachers' knowledge about allergies with an emphasis on the importance of anaphylaxis. It is important to understand teachers' abilities to help students in a potentially life-threatening situation caused by severe allergic reactions that can happen in the school environment.

The research question that was addressed in this study was: *Does a short theoretical and practical intervention programme significantly influence pre-service teachers' knowledge about allergic diseases with an emphasis on anaphylaxis?*

The sample consisted of 62 post-graduate pre-service primary and lower secondary school teachers (all female; average age 24.8; *SD* = 1.1). Similar to the first study, in the second one, 27.4% of pre-service teachers reported that they have allergies.

The instrument used in the second study was Teachers' Health Competencies Development-Anaphylaxis Management Questionnaire (THCDAMQ). It comprises eight attitude items on managing children's anaphylaxis and seven knowledge items about anaphylaxis. The instrument was developed for this research. The content validity of the THCDAMQ was confirmed by three independent experts in paediatric allergology and science education. Specific parts of the THCDAMQ showed satisfactory reliability (Cronbach α was 0.44 for pretest, 0.51 for post-test, and 0.49 for delayed test).

The research design of this study was a typical pre-post design (Fig. 1), applied in October 2016. THCDAMQ was applied in groups three times, before the intervention, immediately after, and 14 days after the intervention. Students were questioned anonymously in written form. Statistical analysis using Excel and SPSS (parametric and nonparametric tests to determine the significance of the differences) was conducted.

More detailed description of the educational programme in allergy management (presented in the grey square of the research design in Fig. 1) is provided here. The course had the same structure providing information on causes, pathophysiology, and recognition of anaphylaxis and treating of anaphylaxis with emphasise on intramuscular adrenaline. The course lasted about 90 min. With the support of PowerPoint presentation the ex-cathedra lectures with students' active participations in forms of questions and in pair discussions provided details about the anaphylaxis as a rapidly developing severe, life-threatening systemic allergic reaction, in which the immune system responds to otherwise harmless substances. Students got information about food (cow milk, egg, peanuts, tree nuts, wheat, soy, fish, seafood); insect stings and drugs are most frequent causes of anaphylaxis in children. The reaction may begin within minutes of exposure and can rapidly progress to cause airway constriction, skin and intestinal symptoms, and altered heart rhythms. In severe cases, it can result in complete airway obstruction, shock, and death. Anaphylaxis can affect several body systems simultaneously. The skin is involved
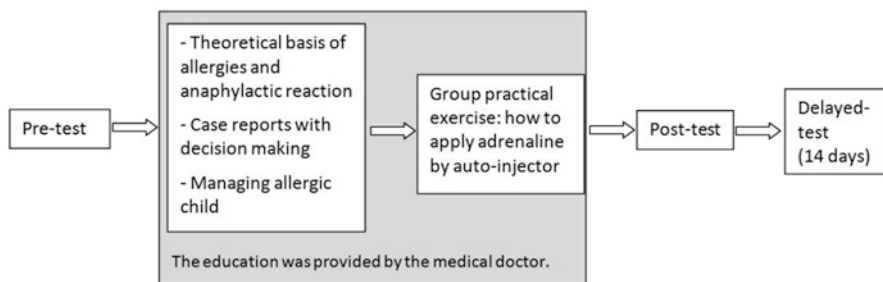

Fig. 1 The research design for the evaluation study

in 80% of anaphylactic incidents in the form of itching, skin rash, and generalised redness or swelling under the skin's surface (angioedema). In other cases the respiratory system may be involved, in the form of irritation and inflammation inside the nose (acute rhinitis) or asthma; the digestive tract (nausea, vomiting, stomach cramps, or diarrhoea) or the cardiovascular system (with palpitations, increased heart rate or low blood pressure) may be involved. These may lead to dizziness, loss of consciousness, and in the worst scenario, to respiratory or cardiac arrest. Clinical criteria for diagnosis of anaphylaxis were also included in teaching (Table 1).

Students were also informed about the proper managing of child with anaphylaxis. This consists of (1) emergency call on 112; (2) proper positioning of child, in most cases, especially when hypotensive, lying down with elevated legs, when vomiting lying on the side, and in case of breathing difficulties, sitting position; (3) applying adrenaline auto-injector; and (4) call to parents. Individual emergency plans and legal aspects of management of allergic child in school environment were also explained.

After the presentation of allergic reactions' theoretical background, students were exposed to the discussion and solving specific cases and answering questions about the topic. These questions were similar to those used in pre- and post-tests, and they were used to repeat the most important aspects of managing child's allergic reactions.

After the lecture students were separated into working groups of eight. Each group has a teaching assistant, and each student practically tries to apply tester of adrenaline auto-injector person to person according to the instructions. If a student was not successful in applying the auto-injector, the teaching assistant tells him to repeat the application.

After the education programme in allergy management, THCDAMQ was applied. Some of the items in the THCDAMQ were similar to those in the study presented by Devetak et al. 2018. The results show that, also in this educational

Table 1 Clinical criteria for diagnosis of anaphylaxis (Sampson et al. 2006)

Anaphylaxis is highly possible if any of following three criteria is met
1. Sudden onset of the disease (in minutes or hours) involving the skin, mucous membranes, or both (e.g. generalised urticaria, pruritis, flushing, swollen lips, tongue, or uvula) and at least one of the following:
a. Impairment of respiratory system (e.g. difficulties in breathing, cough, hoarsens, cyanosis)
b. Impairment of the cardiovascular system (e.g. hypotension, collapse)
2. Two or more of the following, which occur rapidly after exposing the patient to likely allergen (in minutes to hours):
a. Impairment of the skin or mucous membranes (e.g. generalised urticaria, itching, redness, swelling)
b. Impairment of the respiratory system (e.g. difficulties in breathing, cough, hoarsens, cyanosis)
c. Impairment of the cardiovascular system (e.g. hypotension, collapse)
d. Persistent gastrointestinal symptoms (colic abdominal pain, vomiting)
3. Hypotension after exposing the patient to a known allergen (in minutes to hours)

programme on allergic reactions evaluation study, pre-service teachers showed positive attitudes towards learning more about different children's health issues (91.9%). All of them expressed the opinion that child health topics should be very important for each teacher and they all wanted to increase their health competencies. 90.3% thought that the teacher should be responsible for pupils' health issues during school time. Seventy-one per cent reported that they had not been exposed to any activities that would promote their health competencies' development. Similar results were also obtained in the study by Devetal et al. (2018). The results of the Friedman test indicated that there was a statistically significant difference in THCDAMQ scores (χ^2 (2, N = 37) = 48.127, $p \leq 0.000$) between pre-intervention (Md = 3; IQR 2–4.5), post-intervention (Md = 6; IQR 6–6), and 14-day follow-up (Md = 6; IQR 6–6). Key findings suggest that the anaphylaxis educational programme had a positive effect on students' knowledge and attitudes towards children with allergic reactions in school. It is also important to emphasise that pre-service teachers retained stable basic knowledge about anaphylaxis 14 days after the intervention, so it is possible to assume that the intervention is successful with regard to knowledge retention. Similar results were also obtained by (Patel et al. 2006; Lanser et al. 2016; Wahl et al. 2015), but the participants of the educational programme were in-service teachers, and their knowledge retention was not as stable as in our study. The intervention course also had a positive effect on pre-service teachers' attitudes towards schoolchildren's allergy.

Conclusion

The purpose of this chapter was to introduce two studies of pre-service knowledge and attitudes towards managing children's potentially life-threatening allergic reactions in the school environment. Poorly developed teachers' competencies for managing children's allergies can pose a significant problem to the well-being of children in the pre-school and school environment.

In the first study, pre-service teachers expressed the need for developing medical competencies. The duration of undergraduate education, science background, and having an allergy did not influence the level of knowledge regarding the management of allergic children. Pre-service teachers showed an average level of knowledge and skills about allergic child management (e.g. how to recognise if a child has severe allergic reaction, they do not know how to manage this situation and when and how to apply adrenaline by auto-injector if the child has this medicine prescribed by the paediatric allergist), but they expressed a high level of positive attitude and a need to be educated about these topics.

However, the first study showed a need for effective educational programmes capable of developing adequate health competencies, as kindergarten and school personnel are expected to be able to provide first aid in the kindergarten/school environment. As mentioned above, teachers' health competencies (theoretical knowledge, practical skills, and attitudes) influence their values, behaviours,

communication, aims, and practices in schools. Due to these aspects, a model of teachers' key medical competencies (KMC) for students' allergy management was developed and presented on a specific case of managing allergic reactions in the school environment (Fig. 2). This model could be adapted to other medical topics because teachers might be needed as first responders, e.g. in cases of injuries, intoxications, infection, fever, or pain occurring in children or when other chronic diseases or conditions worsen in the classroom demanding immediate response (e.g. in epilepsy, diabetes, asthma, behaviour, emotional disorders, etc.).

Following this model, a second study was developed, and the main findings showed the importance of a short but effective educational programme for pre-service master students before entering their profession in schools. It was also determined that students show a significant level of knowledge 14 days after the educational programme intervention. It is evident that basic training on allergy and anaphylaxis supports pre-service teachers in remembering specific facts also after a longer time after the intervention. This could mean that these pre-service teachers will be able to act more efficiently if they encountered an anaphylactic reaction during their teaching at the school.

If we expect teachers to effectively offer their students first aid in different medical situations, we should provide European legislation that school staff would be indemnified against prosecution for the consequences of administering first aid including applying emergency medication. There is currently no European legislation dealing specifically with the allergic child at school. National legislation varies considerably between European countries. A central issue is the conflict that
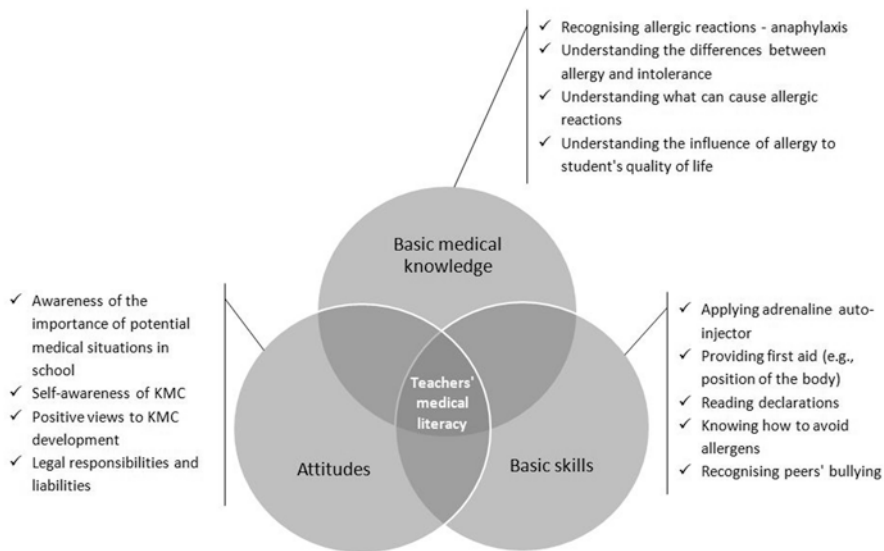

Fig. 2 Model of teachers' key medical competencies (KMC) – students' allergy management

exists between the teachers' legal responsibilities and liabilities in administering medication at school and the child's need for care and privacy.

Under current regulations, teachers have no specific obligations in terms of child health protection because of their lack of medical training. Teachers, therefore, do not have any particular liability above and beyond that of anyone who happens to be present when a child needs care.

Further research into developing teachers' health competencies (following the model in Fig. 2) in different areas of medicine should be conducted. It is also important to emphasise that further research should provide evidence about pre-service teachers' competencies for students' allergy management in the school environment after some months to confirm the persistence of acquired knowledge and to determine the adequate frequency of applications of an educational programme to refresh teachers' medical competencies. There is also a need to develop further and validate a multidisciplinary educational programme. Pre- and in-service teachers' quality of life when they teach an allergic child and how pre- and in-service teachers perceive allergic students' quality of life that can influence students' school achievements should also be explored. Some preliminary results for Slovenian pre-service teachers' quality of life have already been presented (Posega Devetak et al. 2017). Results show that pre-service teachers recognised reduced health-related quality of life of allergic children and expressed also their lower health-related quality of life when taking care for allergic child. There was also no significant correlation between knowledge and health-related quality of life assessment. Following these results health-related quality of life issues should be included into recommendation for the management of allergic child in school, besides training how to prevent, recognise, and manage allergic reactions. It is also necessary to bear in mind that a university elective course for pre-service teachers for developing basic medical competencies should be developed, implemented, and evaluated in the future, leading pre-service teachers to adequately manage medical issues in school environment.

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