PICoSTE
Promoting Instructional Coherence in
Science through Teacher Education

Final Report of the PICoSTE Project

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1. Introduction and Project Overview

Today's world is increasingly dominated by scientific and technological developments. In addition to being a primary economic driver in Europe and beyond, many of the major problems affecting society today are scientific in nature. Tackling global challenges like climate change will require the work of scientists and engineers with expertise in understanding the complex science behind climate change and the design of new technologies for harvesting sustainable energy resources. Equally important, a scientifically literate population must be capable of understanding the core scientific ideas that affect global climate and the process by which scientific understanding and technological solutions are developed and refined through the science and engineering process. School science, therefore, has a dual responsibility for preparing students for future learning in science and for using scientific ideas and ways of thinking to illuminate societal issues (Roberts & Bybee, 2011). Thus, science education in schools must not only teach the core ideas of science, it must involve students in learning in ways that are motivated by relevant and meaningful problems and involve students in the collaborative process of constructing new scientific understanding and designing new solutions, especially through the use of technology (Vuorikari, Punie, Carretero, & Brande, 2016). Yet, science instruction has commonly failed to meet these objectives (Banilower et al., 2018; Osborne & Dillon, 2008). Students' early interest in science often wanes throughout their years in school, and the pipeline to scientific and technological careers is notoriously leaky, particularly among underrepresented groups.

The PISA 2015 Results in Focus report (OECD, 2016) stresses that high-quality school science instruction is critical for promoting achievement, motivation, and equity in science education. There is broad consensus in the science education research community that such high-quality instruction includes situating student learning within investigations of meaningful phenomena and contexts, leveraging these contexts to motivate within students a need to know about new science ideas, and building a relatively small set of core science ideas and practices over a long period of time. Such features are among the hallmarks of "coherent" science instruction (Fortus & Krajcik, 2012; Kali, Linn, & Roseman, 2008). Coherence may be manifest in a variety of instructional models, including 5E (Bybee et al., 2006), project-based science (Krajcik & Czerniak, 2013), and ambitious science teaching (Windschitl, Thompson, Braaten, & Stroupe, 2012). There is a strong and growing base of empirical evidence which suggests that coherent instruction is a major predictor of student learning in science (Furtak, Seidel, Iverson, & Briggs, 2012; Harris et al., 2015; Schmidt, Wang, & McKnight, 2005). The importance of coherence in science instruction is increasingly reflected in science standards documents which in recent years have focused more intensively on building a small set of core ideas over time and across a range of different instructional contexts (KMK, 2005; National Research Council, 2012) – a key factor in instructional coherence. Despite the promise of coherent science instruction and the widespread emphasis on its underlying principles in science teacher education programs and science standards documents, it is seldom enacted in schools (Banilower, 2019; Crawford, 2007; Feldon, 2007; Fischer, Labudde, Neumann, & Viiri, 2014; Gunckel & Wood, 2016).

The Promoting Instructional Coherence through Science Teacher Education (PICoSTE) project was a response to the dichotomy between the type of instruction advocated within science education research and standards documents and what is commonly found in schools. Funded through Erasmus+ Key Action 2: Cooperation for Innovation and the Exchange of Good Practices, the central goals of PICoSTE were to explore the role that science teacher education plays in promoting the enactment of coherent science instruction in schools and to exchange promising practices in science teacher education for promoting preservice teachers' knowledge about coherent science instruction and their ability to enact coherent instruction in practice.

Design and implementation of the PICoSTE Project

In this section, we briefly describe the principles by which the PICoSTE project was designed and describe how these principles were put into practice as the project was implemented. PICoSTE was a collaboration between seven institutions mainly located in the Baltic region, these are:

- Leibniz Institute for Science and Mathematics Education (IPN); Kiel, Germany (lead institution)
- University of Bergen; Bergen, Norway
- Halmstad University; Halmstad, Sweden
- University of Helsinki; Helsinki, Finland
- University of Copenhagen; Copenhagen, Denmark
- University of Uşak; Uşak, Turkey
- University of Duisburg-Essen; Essen, Germany

The core work of PICoSTE involved eight two-day transnational meetings that included a kickoff meeting, five visits to partner institutions (in Sweden, Norway, Denmark, Germany, and Finland), a conclusion meeting, and a meeting focused defining next steps and the scope of future work. In planning and carrying out our work, we reviewed key principles for designing and enacting coherent science instruction and adapted these principles for use in the context of science teacher educator professional learning. We identified three key design principles for promoting coherence that would be particularly relevant for the PICoSTE project: (1) utilizing a "driving question" to provide an overarching framework for the project, (2) focusing on core ideas in the discipline, and (3) generating and recording artifacts of our learning.

Using a driving question.

A driving question is intended to situate and motivate learning as well as promote greater connections between learning activities (Krajcik & Shin, 2014). Our driving question was "How can teacher education experiences better prepare new science teachers to implement coherent science instruction?" To address this question, we grounded our work within our local contexts and focused on relevant phenomena within science teacher education.

One such phenomenon, which was central to our project, is the finding that many new teachers are quick to discard pedagogical strategies and approaches emphasized within their science teacher education program in favor of approaches that are more traditional and less coherent (Fletcher & Luft, 2011; Gunckel & Wood, 2016).

As we worked to explore this phenomenon and shared strategies for how to address it, we involved a variety of stakeholders throughout the project, which helped to ensure that our work was grounded in local contexts. These stakeholders included teachers, administrators, non-university-based teacher educators, pre-service teachers, and local businesspeople. Individual partner visits were planned using coordinated planning, in which the lead partner from each institution would plan collaboratively with the PICoSTE project leader in order to maintain continuity across meetings by ensuring that the goals and outcomes of each meeting were consistent with the broader project goals and related to the project driving question.

Conducting partner visits.

Consistent with our use of a driving question to frame our work, each partner visit focused on a component of the question that was aligned with the expertise and practices in use at each partner institution. Table 1 lists each partner visit and its focus.

Focusing on core ideas.

As a second design principle, we grounded our work in the core ideas of coherent science instruction and science teacher education. To do this, each meeting was preceded by reading several seminal articles that connected the topics to be addressed within the broader literature base. For example, in preparation for the kickoff meeting, all participants read three articles that addressed the topic of coherence in science instruction from different perspectives. At the meeting, we discussed common features of these articles and based on this discussion, we constructed a working definition for instructional coherence that would guide our work going forward. In each subsequent meeting, leaders from partner institutions met with the project leader to identify theoretical and empirical articles that focused on the core ideas to be addressed at the upcoming transnational meeting. We worked to select articles that were not only relevant to the core ideas to be addressed, but were also widely circulated and/or cited within the literature. This additional criterion helped us to ensure that the ideas presented within selected papers had already had substantial impact on the field or had the potential to do so. A list of the articles discussed at each meeting is given in Appendix A.

Learning artifacts.

Our third key design principle included a focus on creating and recording artifacts of our shared learning. Throughout our work, we created shared online documents, recorded careful notes and photographs from each meeting, and constructed models and other representations of our learning. In our kickoff meeting, we created collaboratively-edited documents that recorded our operational definition of instructional coherence, and these documents were iterated in future meetings as needed. Further, we began with the end in mind by recording in writing what we felt it would look like to “answer” our driving question both for ourselves and the broader community. During each partner visit, we held reflective conversations during which we recorded key learning from that meeting and messages that we felt should be shared with the broader community of science teacher educators. A central artifact of our learning was the iterative development of a theoretical model, begun during the third transnational project meeting (the partner visit to the University of Copenhagen) that identifies key elements of science teacher education programs that promote coherent science instruction and represents relationships between

Table 1: List of each partner visit and its focus

Meeting	Date	Meeting focus
Kickoff Meeting	Oct. 30-31, 2017	This meeting focused on introducing the project driving question, drafting an operational definition for coherent science instruction, clarifying project goals and outcomes.
Partner visit: Halmstad University	Feb. 7-8, 2018	This meeting focused on how technology supports coherent science instruction (with an emphasis on digital tools for engaging in scientific modeling) and how preservice teachers can be supported in developing technological pedagogical content knowledge, or T-PACK.
Partner Visit: University of Bergen	April 25-26, 2018	This meeting had two primary foci: (1) supporting pre-service teachers in designing coherent instruction (with an emphasis on the role of demonstrations in motivating investigations of phenomena), and (2) how partnerships with local organizations can support coherent instruction through exposing students to real-world phenomena and design challenges.
Partner Visit: University of Copenhagen	Sept. 24-25, 2018	The focus of this meeting was to begin the development of a model for coherence structured on the research and experiences from successive partner institutions.
Partner Visit: University of Duisburg-Essen	Nov. 28-29, 2018	This meeting had two main foci: (1) coherence between the knowledge the pre-service teachers learn at university and the knowledge they need for enacting teaching and learning in a classroom, and (2) coherence between different phases of teacher education.
Partner Visit: University of Helsinki	March 11-13, 2019	This meeting focused on the process of mentoring pre-service science teachers and collaboration between school and university faculty.
Conclusion meeting	May 31 - June 1, 2019	The purpose of this meeting was to reflect on learning within the project and to begin formalizing conclusions and outcomes to share with the broader community.
Future directions	June 17-18, 2019	This meeting focused on identifying concrete opportunities and strategies for future collaboration that builds off our shared learning within the PICoSTE project.

these elements. Throughout the project, the generation and recording of artifacts helped to document our learning, maintain a focus on addressing our driving question, enhance connections between project meetings, and serve as a critical vehicle for reflection.

Structure of this report

This report is intended to provide an overview of the key theoretical and practical outcomes of the PICoSTE project. Chapter 2 provides a detailed discussion of the theoretical foundations of our project and of the theoretical model that we developed and iterated throughout the course of the project. In addition to explicating the theoretical foundations and perspectives for our work, the model serves as a map to illustrating relationships between components of science teacher education that are promising for supporting the enactment of coherent science instruction in schools. Chapters 3 through 7 are dedicated to elaborating key components and practices in science teacher education programs at partner institutions that were highlighted during the PICoSTE project. Each of these chapters provides a brief overview of the local context for science education and science teacher education, describes key practices for supporting the enactment of coherent science instruction, and links these practices to the overarching theoretical model and perspectives outlined in Chapter 2. Finally, Chapter 8 summarizes key outcomes from the PICoSTE project and considers ways forward as science teacher educators work collaboratively to develop new strategies, perspectives, and practices that prepare new teachers for enacting coherent science instruction in their own classrooms.

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2. Toward a Theoretical Model for Promoting Instructional Coherence through Science Teacher Education

In the PICoSTE project, we have focused on the role that science teacher education can play in resolving the dichotomy between the type of coherent instruction emphasized within the science education literature and the instruction commonly observed in schools. In this chapter, we review relevant literature and, based on our shared work in this project, present a tentative model for identifying key features of science teacher education that may help new science teachers successfully enact coherent science instruction.

What should new science teachers know and be able to do?

In recent decades, there have been a series of shifts in the emphases of science teacher education programs, leading to the current dominant paradigm, which stresses teachers' development of particular knowledge and skills, such as pedagogical content knowledge (PCK) (Lederman & Lederman, 2015). However, there is an ongoing debate in science education research what facets and ideas of PCK should be considered in the development of preservice teachers (e.g. Kind, 2009). In a first effort to synthesize various ideas about PCK, a summit was held in 2012 resulting in a "model of teacher professional knowledge and skill" (Gess-Newsome, 2015), which became also known as the 2012 PCK consensus model. This model distinguished explicitly between broader knowledge bases like content knowledge (CK) and topic-specific professional knowledge (TSPK) and the knowledge and skills used in science classroom (personal PCK and PCK/Skill). While PCK was located in a bigger model in the classroom context, the consensus model provided little information about the different facets and aspects of PCK itself. In response to this shortcoming, a second summit was held in 2016, where science educators discussed the specific aspects of PCK in more detail, resulting in the "Refined Consensus Model of PCK" (RCM) (Carlson & Daehler, 2019).

In the RCM, different realms or layers of PCK are identified: collective PCK (cPCK), personal PCK (pPCK), and enacted PCK (ePCK). These different realms of PCK are separated but interrelated and located within the broader professional knowledge bases for teaching such as CK and general pedagogical knowledge. The RCM therefore accounts that the foundation of teaching a certain topic is still a profound knowledge about this topic, its relationship to other topics and epistemological foundation (i.e. compromised as CK). In order to make the content comprehensible to students, teachers also need an understanding of how to represent this content to learners, strategies for supporting student investigations, etc. (Shulman, 1986). cPCK represents the first realm of that knowledge and is the public knowledge generated by science education research and best practice (see also Gess-Newsome, 2015) and is therefore part of lectures and seminars of university teacher education. In a second layer, pPCK comprises the cumulative knowledge of an individual teacher gathered in formal learning opportunities and practical experiences. In the center of the model is ePCK as the knowledge and skills teachers use preparing, enacting and reflecting on a specific lesson with specific students.

For teacher education to account for these different realms of PCK, several learning opportunities are necessary to facilitate cPCK to preservice teachers and strengthen their pPCK.

The recognition that science teacher education should focus on building the special knowledge base needed for teaching science has been recognized as necessary, but not sufficient, by researchers who have investigated the role of teachers' beliefs in mediating knowledge exchanges between the different realms of PCK as well as mediating teachers' planning and classroom-based decisions (Enderle et al., 2014; Milner, Sondergeld, Demir, Johnson, & Czerniak, 2012; Richardson, 1996; Sang et al., 2012; Veal, Riley Lloyd, Howell, & Peters, 2016). Fletcher and Luft (2011) argue that science teacher education should explicitly attend to challenging the (typically more traditional) beliefs about teaching and learning held by preservice science teachers, and they report that beliefs about science teaching may be substantially influenced by science teacher education experiences, particularly when these experiences are closely connected to field-based practice.

While not disputing the importance of knowledge and beliefs, Hutner and Markman (2016, 2017) argue that they are insufficient to explain the observed discrepancies between research and practice, that is, that teachers' espoused beliefs and their observed practice often conflict, particularly for new teachers (Crawford, 2007; Davis, Petish, & Smithey, 2006)Using a goal-driven framework, Hutner and Markman (2017) argue that knowledge and beliefs must be activated in order to influence practice, and that different goal orientations between the university environment and the school environment may help explain discrepancies between teachers' self-reported preferences and their observed instructional characteristics.

Whether science teacher educators emphasize the importance of knowledge for teaching, beliefs, or goal orientations, there is broad agreement that all three constructs cannot be effectively developed solely in the university classroom – these critical competencies and orientations require thoughtful engagement in school-based practice (Gunckel & Wood, 2016; Hutner, Petrosino, & Salinas, 2019).

Supporting coherent science instruction through teacher education

High quality field experiences are critical for developing a consistent set of knowledge, beliefs, and goals that are important for both planning and enacting coherent science instruction, yet, the school-based components of teacher education are often poorly connected to university-based components (Zeichner, 2010). This lack of connection represents a significant barrier for new teachers to overcome if they are to enact coherent science instruction in practice. Darling-Hammond (2006a) argues that teacher education programs that prepare preservice teachers for the complexities of in-service practice are characterized by three components: coherent and well-integrated course work and field experiences, extensive and well-supervised field experiences which connect theory to practice, and close relationships with schools and mentor teachers. For science teacher education programs to be effective, they must also promote new pedagogies, which are not commonly found in schools, and which are more engaging and focus on students' effective engagement with scientific phenomena (Evagorou, Dillon, Viiri, & Albe, 2015).

Coherence in science teacher education.

Just as coherence is a key factor in effective school science instruction, it is a hallmark of effective teacher education as well (Darling-Hammond, 2006b). A key feature of coherence in teacher education is conceptual coherence, meaning that teachers encounter a small set of core ideas about science instruction across a range of experiences. Encountering and using the same set of ideas across contexts is key to learning and transfer (Bransford, Brown, & Cocking, 2000), and coherent teacher education programs structure preservice teachers' experiences so that they encounter, and have opportunities to use, core programmatic ideas in multiple settings and tasks. Tatto (1996) provided some evidence that teacher education programs which emphasize a small set of core ideas about learning influence preservice teachers' beliefs to be more in line with core programmatic ideas, but did not explore the influence of these beliefs on teachers' practices. Subsequently, Hammerness (2006) investigated the teacher education program at one institution and reported that graduates' teaching practices resembled the core ideas emphasized within the program, providing evidence that core programmatic ideas translated into practice.

Structural (e.g., organizing and aligning courses) and conceptual coherence (e.g., focusing on a small set of core ideas about learning) are important factors in effective science teacher education (Feinam-Nemser, 1990; Hammerness, 2006), but these factors alone are not enough; science teacher education programs themselves should be perceived as coherent by the preservice teachers who experience them. In an international comparison study, Canrinus, Bergem, Klette, and Hammerness (2017) reported that preservice teachers perceived a reasonable amount of coherence between courses at the university, but that coherence between university and field experiences was generally less apparent. A fundamental challenge for supporting new teachers' readiness to enact coherent science instruction is that this type of instruction is not common in schools; simply including field-based experiences in science teacher education is unlikely to provide new science teachers with the opportunity to develop and refine the skills and dispositions necessary for designing and enacting coherent instruction of their own. Recognizing this, PICoSTE partners have collaborated to identify key programmatic components of science teacher education that help to bridge between the intended and enacted coherent curriculum. In the process of identifying and discussing these programmatic components, we constructed a model that situated these components relative to each other within the broader context of science teacher education that might better support the enactment of coherent instruction in schools.

A proposed model for science teacher education that promotes coherent instruction.

The model in Figure 2.1 identifies the key elements of science teacher education that hold promise for supporting the enactment of coherent science instruction and illustrates their relationship to each other.

Our model illustrates that science teacher education consists of four main components: (1) background fields that represent the university and school context, represented as blue circles, (2) intended and enacted coherent curriculum and associated activities in these different contexts, represented as rectangles, (3) a "reflective dynamo" represented by a triangle with embedded dashed double-headed arrows, and (4) bridging components represented by solid double-headed arrows. The background fields overlap, representing that science teacher education occurs within both the school and university contexts and that core elements of effective science teacher education are firmly embedded within both contexts. While science teacher education nearly always occurs within these two contexts, the overlapping of these two contexts indicates that in order for science teacher education to support the enactment of coherent instruction, preservice teachers must be afforded opportunities to engage work consistently in both contexts.

We place the intended coherent science curriculum within the university context (where preservice teachers would largely encounter these ideas) and the enacted coherent science curriculum within the school context (as it is only in here that enactment can happen). Learning about intended coherent curriculum largely happens through university coursework, and this learning should include opportunities to review exemplary coherent curriculum designed for the local context, to deeply explore relevant standards documents through activities such as "unpacking standards" (Krajcik, McNeill, & Reiser, 2008), and to become familiar with seminal research that lays theoretical and empirical foundations of coherent curriculum. Within the context of science teacher educati-

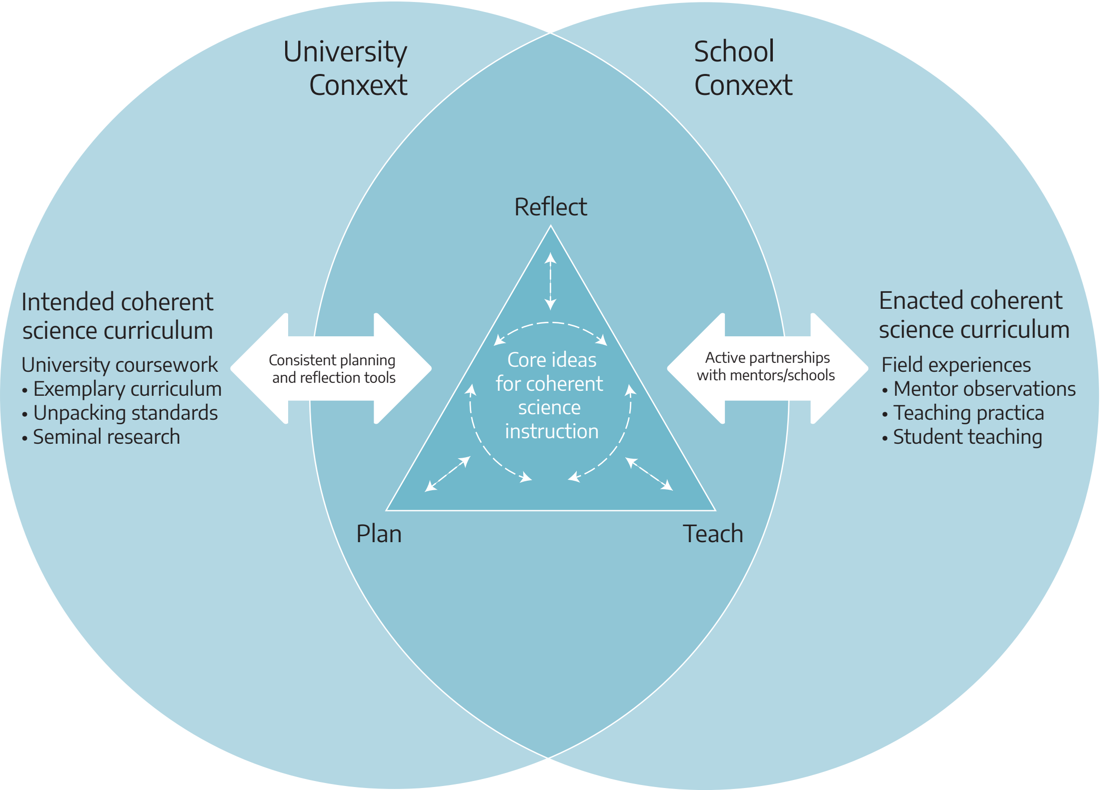

Figure 2.1: Program features and tools for bridging between school and university contexts to support coherent science instruction.

on, experiences with enacted coherent science curriculum occurs within guided field work, such as observations of mentor teachers' instruction, shorter-term teaching practica in which preservice teachers are responsible for smaller teaching modules, and longer term student teaching placements where preservice teachers plan and implement full instructional units.

At the center of the model, and situated within both the school and university contexts, is a reflective dynamo that is guided by a small set of core ideas for coherent science instruction and that is manifested through the professional activities of planning, teaching, and reflection. Core ideas for coherent science instruction include the hallmarks of coherent science instruction (situating learning within meaningful phenomena, motivating students' need to know, and building a small set of core science ideas over time), but the specific core ideas within each science teacher education program may vary based on local context. For example, the German science education standards (e.g., KMK, 2005) prioritize a few "basic concepts" [Basiskonzepte] that should permeate disciplinary instruction and be built over time, but the central role of these concepts in science education might not be emphasized in other countries. While the specific core ideas for coherent science instruction may vary somewhat across contexts, they are manifest through preservice teachers' reflections on theory and practice, planning science instruction, and teaching practices. These three professional activities manifest in different ways based upon the context, and not all three need to happen within the scope of all science teacher education activities. For example, there is value in preservice teachers reflecting upon a set of pre-developed plans based on the core ideas for science instruction, even if they do not enact those materials in practice.

The core activities of planning, teaching and reflection around a core set of instructional ideas are connected to the intended and enacted coherent science curriculum through bridging components, represented as double-headed arrows. These bridging components comprise explicit links between the school and university contexts and help to align intended and enacted coherent science curriculum via the reflective dynamo that drives teacher learning. Connecting this reflective dynamo to the intended coherent curriculum are planning and reflection tools that scaffold these professional practices and align with the core ideas for coherent science instruction. Such tools include the CoRe (Hume & Berry, 2011), which helps preservice teachers in identifying which ideas are most important within science instruction and how to represent them to learners. A key bridging component linking the reflective dynamo to the enacted science curriculum is active partnerships between university faculty and mentors at schools. These partnerships are most effective when school and universities have structural components in place to support meaningful collaboration and exchange around the core ideas for coherent science instruction.

Summary

In order to promote the knowledge and skills necessary for enacting coherent science instruction in schools, science teacher education programs must themselves be coherent. We have identified key elements for supporting conceptual and structural coherence in science teacher education, and we have arranged these elements within a model for science teacher education that might better support new teachers in enacting coherent science instruction. Supporting teachers in their planning and reflection and linking field practices with university coursework were transcendent features of teacher education, which need to take national educational contexts into account and need to be formulated for each teacher education program specifically.

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3. Coherently Using Digital Technologies in Learning Environments

Halmstad University, Sweden

It is widely accepted that all students should leave school with a basic understanding of the ideas and procedures of science. School science should be engaging and relevant and enable students to be actively involved in inquiring and making decisions about the world around them. Further, school science that meets future needs of students in the 21st century should engage with contemporary scientific practice and enable students to gain insights into science that addresses real-world questions. In Sweden, the new national curriculum for compulsory school was implemented in 2011. The curriculum contains general goals, guidelines, syllabi, and knowledge requirements concerning both science content and skills. In the Swedish curriculum, science is separated into three subjects: biology, chemistry, and physics. Different aims, core content, and knowledge requirements for these subjects are presented in the curriculum from 2011. Summaries of aim and core content for each subject are presented below.

In biology, the students should develop their ability to:

- Use their knowledge of biology to examine information, communicate, and form an opinion on questions concerning health, the use of natural resources, and ecological sustainability
- Carry out systematic studies in biology
- Use concepts of biology, its models, and its theories to describe and explain biological relationships in the human body, nature, and society

In chemistry, the students should develop their ability to:

- Use their knowledge of chemistry to examine information, communicate, and form an opinion on questions concerning energy, the environment, health, and society
- Carry out systematic studies in chemistry
- Use concepts of chemistry, its models, and its theories to describe and explain chemistry in society, in nature, and in people

And, in physics, the students should develop their ability to:

- Use their knowledge of physics to examine information, communicate, and form an opinion on questions concerning energy, technology, the environment, and society
- Carry out systematic studies in physics
- Use concepts of physics, its models, and its theories to describe and explain physics in nature and society

In addition to the different aims, core content, and knowledge requirements for the science subjects, a strong focus on digital technologies in school, places demands on teachers´ and students´ knowledge and abilities while also creating new educational opportunities. In October 2017, the Swedish government decided on a National Strategy for digitalization of the school system. The strategy provides a more comprehensive approach to digital skills development as well as access to and use of digital technologies in all stages in the school system. The goal is for Sweden to be world leader in using the opportunities that digitalization offers. In March 2017, the government approved the new curriculum for K-9 Education, which was implemented by Fall 2018. The revised curriculum introduced digital competence and programming as interdisciplinary traits between different school subjects such as math and technology, language and social sciences. The curriculum also provides explicit formulations in subjects such as mathematics (programming, algorithms, and problem-solving), technology (controlling physical artifacts), and social studies (fostering aware and critical citizens in a digital society). In the Swedish national curriculum for schools, digital competence includes four aspects: 1) understanding how the digitalization affects individuals and society, 2) understanding how to use digital tools and media, 3) critical and responsible usage of digital tools and resources, and 4) being able to solve problems and implement ideas in practice. In the national curricula for school science, digital tools are embedded into activities around visualizations, experiments, communication, and demonstrations.

In the Swedish science classrooms, tools such as computers and iPads, digital microscopes, multimedia, student response systems, and interactive white boards are actively used to help students actively engage in both the acquisition of scientific knowledge and development of inquiry skills. Research indicates that when educational technology tools are used appropriately and effectively in science classrooms, students actively engage in their knowledge construction and improve their thinking and problem-solving skills (Trowbridge, Bybee, & Powell, 2008). For example, using simulations can help create new opportunities to prepare science experiments and laboratory work, and provides great opportunities and positive effects on students´ engagement and learning (Geelan et. al., 2014; Rutten et. al., 2012). Further, when students experience activities that are not possible to experience in the real world (e.g. virtual reality), they are provided with an opportunity to learn a more abstract content.

As a consequence of the strong focus on digital technologies, there is a growing demand on professional development for Swedish teachers to better meet the needs in the government´s National Strategy for digitalization. The number of good examples in several Swedish classrooms focusing ways in which science learning can be enhanced through digital technologies are increasing. For example, 3-D animations and simulations can help make abstract concepts more visible, apps can allow the easy manipulation of variables and formulae, digital probes and motion sensors can collect accurate data systematically, virtual labs give more ready access to laboratory or industry processes, and virtual networking enables students to connect and collaborate with each other and others including scientists. In summary, in order to create coherent learning environments when using different tools, science teachers need to try new ideas and explore the possibilities enabled through digital technologies.

The context of science teacher education

In Sweden, the teacher education program consists of three parts: studies of subject matter and pedagogical content knowledge (PCK), studies of educational science, and teaching placements. The science and science education courses contain areas of knowledge related to the grades the student teacher has chosen to become a teacher in. In these courses the student teachers develop their knowledge of, in, and with science as well as how, why, and for whom they are teaching. The student teachers will gain concrete expertise in science education (e.g., PCK), as well as science subject knowledge. Educational science contains areas of knowledge central to the teacher and preschool teacher professions. These courses are built around leadership, assessment, special needs knowledge, theoretical perspectives on learning, etc. The courses in educational sciences provide students with expertise in the more general aspects of teaching. Finally, the teaching placement consists of 20 weeks during a four (primary) to five (secondary) teacher education program. During the teaching placement, the student teachers participate in the everyday work of a school/preschool teacher. The student teachers have the opportunity to connect their theoretical knowledge to practical use and to practice important skills concerning their roles as teachers.

There are several different teacher education programs depending on the age of the students the teacher will teach. All programs have 30 ECTS (20 weeks) of school practice. The preschool teacher education is a three-year program whereas 15 ECTS is dedicated to science and technology. The two primary teacher education programs (year 6-9 and 10-12) are four years whereas 30 ECTS are dedicated to science and technology. For upper secondary school (13-18), there is a five-year program where the student teachers are studying two science subjects. Finally, there is a 1,5 years post-graduate program for those students who already have a master’s in science, mathematics, or technology.

The teacher education programs qualify for teaching on different grade levels and differ in regard to number of school subjects, the minimum number of ECTS in each subject, and the amount of school practice during the studies (see Table 3.1, Page 20).

As indicated in Table 3.1, the teacher education programs in Sweden are built around the idea of coherently integrating content, PCK, educational sciences and school practice. For these parts to be successfully integrated, reflective activities are provided during the whole teacher education program. As such, science teacher education provides coherent core-ideas, both within well-aligned coursework and within the school-based practice, making explicit the different dimensions of, and links between the knowledge of content and the knowledge of teaching and learning about that particular content.

The quality of reflection and the support in reflecting classroom experiences can be viewed as important for acquiring professional knowledge and skills in the context of practice. During the teaching practice, the student teachers are offered opportunities for learning through different types of supervision. The supervision is based on the student teachers´ intentions and questions in a continuous dialogue between the mentoring teacher and the student teacher. The goal is for the student teacher to develop his or her ability to observe and critically examine other people´s and their own teaching practice. The mentor should be supportive and give clear and constructive feedback that is both affirming and developing the student teachers´ professional knowledge in relation to the goals of the course. In order to give the student teacher the opportunity to learn as much as possible during his/her teaching practice, the mentor´s assessment and feedback takes place continuously during the period and focuses on formative assessment practices.

Consequently, the Plan-Teach-Reflect model, described in the theoretical model undergirding this PICoSTE project, is important in order to bridge the gap between the university context

Table 3.1. Teacher education in Sweden

Program	Number of teaching subjects	ECTS in subject	Compulsory courses / ECTS	School practice /days
3,5- year bachelor’s	4	Minimum 7,5	Science education / 15	100 regular School practice days and each year 8 - 12 additional preparation days in the schools.
4-year bachelor’s grade 0 - 3	5	Minimum 30 in four subject and 15 in one	Pedagogy and student related knowledge / 75 Science education / 30	95 regular School practice days and each year 8 - 12 additional preparation days in the schools.
4-year bachelor’s grade 4 - 6	4	Minimum 30	Pedagogy and student related knowledge / 72 Science education or Social science education / 30	95 regular School practice days and each year 8 - 12 additional preparation days in the schools.
5-year master’s grade 10 - 13	2	Minimum 90	Pedagogy / 60 and science education / 15	70 regular School practice days

and the school context, and further, to provide opportunities for student teachers´ professional knowledge development.

Further, the active partnerships with mentors and schools (right circle in the model) is strongly developed at Halmstad University through so called “Practice schools” similar to the Finish model described in this report. Activities with practice schools and preschools started in the fall of 2014 and have been gradually expanded to involve all student teachers for preschool and primary school studying at Halmstad University. The overall goal of the specific practice schools is to increase the quality of teacher education and to strengthen the professional development of student teachers through closer collaboration between the university and selected preschools and schools. Closer collaboration should also contribute to strengthening the quality development of preschools and schools, as well as helping teacher education to better bridge the gap between theory and practice.
In relation to the teacher education at Halmstad University, there has been several research projects on student teachers´ and teacher

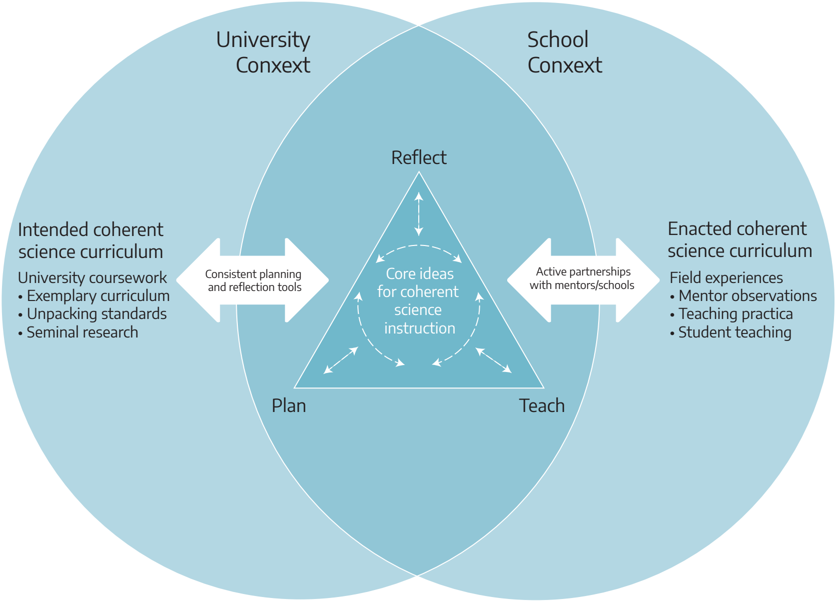

Figure 2.1: Program features and tools for bridging between school and university contexts to support coherent science instruction.

educators´ learning about teaching, the relationship between different elements that constitute teacher knowledge and how these are captured and understood during teacher education programs (e.g. Nilsson, 2008, 2009; Nilsson & Karlsson, 2018; Nilsson & Loughran, 2012). As such, the research carried out at Halmstad University relates to different aspects of the theoretical model above.

Digital technologies at teacher education at Halmstad University

Shulman (1986, 1987) introduced the term “pedagogical content knowledge” (PCK) to draw attention to the value of the special amalgam of content knowledge and knowledge of general pedagogy that a teacher needs in order to be the best possible teacher. It is the knowledge that teachers activate when they plan particular lessons on a specific topic and when they reflect upon them afterwards. With this background, pre-service teachers should be coherently encouraged to reflect on their planning and teaching in ways that might help them realize the need for expansion or modification of their planning for teaching a particular topic. Twenty years after Shulman´s introduction of PCK, Mishra and Kohler (2006) argued that teachers need to comprehend the dynamic and transactional relationship between technology, pedagogy, and the subject content in order to be able to integrate technology into teaching. This is expressed as technological pedagogical content knowledge (TPACK). The conception of TPACK adds technological knowledge as a new component that has to blend in with domain and pedagogical knowledge in order to effectively integrate ICT in instructional practices. Within the educational curricula for all teacher education programs it is explicitly formulated that student teachers should develop digital competence to choose and value digital tools and media in their teaching. As such, teacher education is emphasized as crucial for preparing teachers (both pre-service and in-service) to be able to use digital technologies in meaningful ways in their professional activities. However, the results of a recent survey carried out among Swedish student teachers (Demoskop, 2016) indicate that one out of three student teachers experienced that the use of digital tools in their teacher education was low, and nearly half of the student teachers felt that the preparations for teaching with digital resources were inadequate.

At Halmstad University, we use the TPACK framework to stress the importance of formulating teacher competence as an integration of pedagogical, content, and technological knowledge. As the revision of the Swedish national curricula strongly emphasizes digital tools in the teaching of specific school subjects, integrating digital technologies into the content courses at teacher education programs is crucial. Consequently, the conception of TPACK is useful as it adds technological knowledge as a new component that has to blend in with content knowledge and pedagogical knowledge in order to effectively integrate digital technology in instructional practices. Further, in the teacher education at Halmstad University, pre-service teachers are coherently encouraged to reflect on their planning and teaching to encourage collaborative discussion and reflection on what, why, how, when, and for whom in relation to their teaching of science. For the purpose of stimulating student teachers' reflections and developing their PCK, Content Representations (CoRe) has shown to be a useful pedagogical tool (Hume & Berry, 2011, 2013; Loughran et. al., 2006). The CoRe requires the student teacher to reflect upon how to teach a specific topic in order to promote student learning. It prompts student teachers to articulate the 'Big Ideas' relating to queries that include: what students should learn about each Big Idea, why it is important for students to know these ideas, students' possible difficulties with learning the ideas, and how these ideas fit in with the knowledge the teacher holds about that content. In this way, working with the CoRe as a reflective tool has the potential of helping student teachers conceptualize their professional knowledge and make explicit the different dimensions of, and links between, knowledge of content, teaching, and learning about a particular topic.

At Halmstad University, the student teachers are introduced to the CoRe in several courses during their teacher education program. For example, in the course of assessment and general education, the student teachers are discussing and completing a CoRe in a workshop at the university and during their teaching placement they construct a CoRe on a chosen topic. After their four weeks of school practice, they reflect on their teaching in relation to their CoRe and, as such, they self-assess their own development of PCK. In the courses of science education, the student teachers complete a CoRe for planning, teaching and reflecting on a science lesson during their teaching placement. Further, in the same way as in the course of assessment and general education, they reflect on their teaching in relation to their CoRe and self-assess their own development of PCK for teaching science. As our research has demonstrated, working with a CoRe can help student teachers conceptualize their professional knowledge and empower them to actively develop their professional knowledge of practice in specific content (i.e. offer glimpses into their developing PCK) (Nilsson, 2013; Nilsson & Loughran 2012; Nilsson & Karlsson, 2018).

When Loughran and his colleagues designed the CoRe in the early 2000s, digitalization had not yet gained so much attention in the classrooms. Therefore, at Halmstad University we have reworked the original CoRe into a T-CoRe. When a CoRe illustrates and contributes to developing a teacher´s PCK, a T-CoRe illustrates how digital technology can (or cannot) contribute to student learning of a specific subject content (TPACK). In the T-CoRe, two issues have been altered in order to target the use of digital tools in the teaching of science. The original question: "Which teaching methods should you use and for which particular reason have you chosen these methods?" has been changed to: “Which digital teaching methods should you use and for which particular reason have you chosen these methods?” This issue emphasizes the reflection on the choice of digital methods and why these choices have been made in relation to the Big Idea formulated. The second issue that has been added to the original CoRe is: “What opportunities and challenges do you see that the use of digital tools can provide to facilitate students’ understanding of the specific subject content?” This question aims to problematize the use of digital tools in the teaching of science. The T-CoRe itself is a spreadsheet-styled template and the first task for teachers is to identify the Big Ideas associated with the topic. The student teachers discuss and reflect on their own practice to address the pedagogical prompts. Through this process, the student teachers can identify student misconceptions and prior knowledge, and which instructional strategies are most suitable for enhancing understanding. The responses from a completed T-CoRe provide useful insights into a teacher’s TPACK.

Table 3.2. Technological Content Representation (T-CoRe) developed from CoRe.

Theme for teaching Age of the students:	Big Idea A	Big Idea B	Big Idea C
What do you intend the students to learn about this Big Idea?			
Why is it important for students to know this?			
What else you know about this idea (that you do not intend students to know yet)?			
Difficulties or limitations connected with teaching this Idea?			
What is your knowledge about students´ thinking which influences your teaching of this idea?			
Other factors that influence your teaching of this Idea?			
Which digital teaching methods should you use and for what reason have you chosen these methods?			
What opportunities and challenges do you see that the use of digital tools can provide to facilitate the students´ understanding of the specific science content?			
Specific ways of ascertaining students´ understanding or confusion around this idea?			

During a 30-credits course in science and science PCK, student teachers for primary school (grade 1-6) are introduced to the T-CoRe as a tool to capture and understand aspects of the development of TPACK while planning for teaching a particular science topic in the Digital Learning Centre at the university (DLC). The T-CoRe is a reflective tool that is combined with group reflections around the prompts in the T-CoRes where the student teachers are working in groups to compare and discuss their responses and their experiences of teaching in relation to their T-CoRes. For research purposes, over several years we have collected student teachers T-CoRes and video-recorded their reflections to better understand the challenges and dilemmas student teachers experience while learning to teach science through digital technologies. Some examples of student teachers´ experiences are presented in this report. One important aspect of the way we use T-CoRes at Halmstad University is that constructing a CoRe, as well as a T-CoRe, empowers student teachers to become more effective practitioners in the classroom. Within the T-CoRe construction, student teacher collaboration, as another layer of coherence in the theoretical model, is crucial as student teachers can share their individual philosophies and ideas, take responsibility for their professional learning, work in partnerships with each other, and collectively reflect on their practice.

In the data collected on student teachers´ use of T-CoRe we have seen that the T-CoRe as a reflective tool is experienced as valuable in a collegial context to process and discuss the teaching of science with digital technologies. The student teachers highlight the strength of the T-CoRe as it focuses on and describes their abilities and also their challenges in the classroom based on pedagogy, subject, and technology. With the help of the T-CoRe, the student teachers can reason together with their peers and think about what different competencies and abilities they need to identify and develop in order to build and implement their teaching. Within the student teachers´ reflections there are several good examples of how the T-CoRe helped to capture aspects of their TPACK. Below, Kevin describes his experiences working with the T-CoRe:

“The challenge of formulating a good Big Idea such as for example ‘the properties of air’ in the T-CoRe and then answering all the questions has been a bit of an alarm clock. It has primarily helped me to better understand that traditional content knowledge is not enough to be able to teach in a way that promote students´ understanding. In order to be able to answer the T-CoRe questions successfully, I need to understand what students experience as problematic in science. I also need to know which representations, metaphors and demonstrations that can be used to benefit students´ science learning. The questions in the T-CoRe emphasize many important things that a teacher should know.
The way we have coherently integrated CoRe and T-CoRe as reflective tools for student teachers indicates an increased awareness of not only what to teach, but also how and why they should use digital technologies in their science teaching. Further, the student teachers who participate in the 30 credits course in science and science PCK were engaged in questioning their own practice in a way that prompted a coherent use of reflection and practice. This might imply that they begin to identify aspects of their own teaching that makes a difference for their students´ learning of a particular content, and consequently, come up with suitable actions to deal with the problem.

Finally, Canrinus et. al., (2017) noted that a coherent teacher education program is a program in which students are not only able to connect knowledge and skills but also maintain opportunities to investigate new connections and possibilities as well as have the agency to develop their own conceptualization of teaching. It appears that using the T-CoRe design encouraged collaborative discussion and reflection about using digital technologies when teaching certain Big Ideas linked to a topic. As such, it is suggested that the case from Halmstad University presented in this final report is a coherent way to enhance pre-service teachers to collaborate, reflect, and discuss ideas about their practice and instructional strategies.

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4. Aligning University Teaching and Research Partnerships to Support Coherence

University of Bergen, Norway

In this chapter we take a look at science teacher education in Norway. While teaching and teacher education have to abide by laws and regulations on the national level, practices in different institutions can vary to some degree. The described practices to support coherence are local examples from the University of Bergen (UiB). Other teacher education institutions in the country may share the same principles for achieving coherence, but enact them in different ways.

Science education in Norway

Science as a subject is taught throughout compulsory school (grades 1-10) and also in the first year of upper secondary school (Grade 11). The subject includes aspects from biology, chemistry, physics, and Earth science. In grades 1-7, science is taught for 366 hours (increased from 328 hours in 2015). In grades 8-10, the total number is 249 hours (all calculated as 60-minute lessons).

There is a national curriculum for science, which specifies broad areas of study and more fine-grained competence aims for different grade levels. Currently, curricula are under revision with the aim to reduce the amount of different topics; promote the development of crosscutting competences in the fields of democracy, sustainability, and health and wellbeing; and achieve a deeper learning. These aims are in line with what we in PICoSTE regard as coherence in science instruction. The new curricula should become effective in Autumn 2020.

Upper secondary school (grades 11-13) offers science as a general, mandatory subject in the first year. Further on, there are elective, separate science subjects—biology, chemistry, physics, and geoscience—in two year-long courses. Each course consists of 140 hours of teaching. Also, there are national curricula. Examinations in Grade 12 are locally organized by the teachers, while there is a state-wide central examination at the end of Grade 13.

Science teacher education in Norway

Science teacher education in Norway is in transition, especially regarding the education of compulsory school teachers. New state regulations for teachers in compulsory school became effective in 2017. A few years earlier, new state regulations for other teacher education programs were introduced. A main feature of the current regulations is that all teachers have to have a master's degree. There are three different teacher education programs in the form of a 5-year integrated master's program. A second alternative to qualify as a teacher is a 1-year post-graduate study based on a relevant master's degree.

The teacher education programs qualify for teaching on different grade levels and differ in regard to the number of teaching subjects, the minimum number of ECTS required in each subject, and the amount of school practice during the studies (see Table 4.1).

Courses in teacher education at UiB that address the teaching of the science subjects total 15 credits for each school subject the students want to qualify for. For example, courses in the

Table 4.1: Teacher education programs and requirements

Program	Number of teaching subjects	ECTS in subject	Compulsory courses / ECTS	School practice /days
5-year master's grades 1 - 7	3 - 4	Minimum 60 in one subject and 30 in the others	Pedagogy and student related knowledge / 60	Minimum 110
5-year master's grades 5 - 10	2 - 3	Minimum 60 in two subjects and 30 in the third	Pedagogy and student related knowledge / 60	Minimum 110
5-year master's grades 8 - 13	2	Minimum 60	Pedagogy / 30 and subject education / 30	Minimum 100
1-year postgraduate	2	Minimum 60	Pedagogy / 30 and subject education / 30	Minimum 60

subjects of biology, chemistry, or physics are the same as for the respective bachelor's and master's programs. That means they focus on learning the subject, but not on how to teach part of this content in school.

Coherence in science teaching

I (Matthias Stadler) regularly ask student teachers coming to my courses in science and chemistry education about their experiences with and views of science teaching. We also compare the structure of science and mathematics lessons from Norwegian compulsory school (Topphol, 2012; Ødegaard & Arnesen, 2010). Despite some variation, there seems to be a common pattern in science instruction which gets more pronounced in the upper grades. The teacher introduces concepts in relatively brief sessions. Teachers invite pupils to take part in the development of the content, but only those who volunteer are selected by the teacher to contribute. Then, the teacher shows examples of how to apply the new concepts (i.e., how to calculate the pH in an acid solution). After that, pupils work on similar problems alone or together with other pupils. During this work, the teacher circulates the room, answering questions and helping pupils who struggle. In the case that many struggle with the same task the teacher will then show the solution to the whole class pointing out critical steps. Otherwise, the teacher does not check student work in a systematic way. One reason for that is that the pupils have access to the solutions, and it is expected that the pupils take responsibility for their learning.

Student teachers who are good in mathematics often report that learning chemistry for them was easy. Others say that they had to learn a lot by heart and that real understanding came only during their university studies. Some indicate that still some subject areas are difficult for them. My student teachers' descriptions suggest that science teaching in Norway has some challenges regarding deeper understanding of the subject. This is corroborated by research that found that much time in school is used for introducing new knowledge and working with easy tasks like finding information in a text, whereas making connections between different knowledge elements and going into depth is less common (Björnsson & Olsen, 2018; NOU 2014: 7, 2014). These results have led to the current revision of the curricula (Meld. St. 28, 2015-2016; NOU 2015: 8, 2015).

Science educators at UiB agree that teacher education has to introduce student teachers to inquiry-oriented teaching approaches that engage pupils in developing and justifying explanations of phenomena to improve science learning (Furtak, Seidel, Iverson, & Briggs, 2012). Therefore, science education courses at UiB focus on analyzing current teaching practices in school and discussing alternative approaches. The ultimate aim of this is that student teachers understand the thinking behind the approaches, see their potential benefits, and realize how they can try out aspects of them during their practice placements. Achieving this aim requires an integration of learning experiences at university and school, which is often referred to as "bridging the theory-practice gap," indicating that theory and practice are independent realms. However, a view that useful theories emerge from reflection on practice, which in turn help to improve practice, might be more appropriate (Korthagen, 2010). If teacher education wants to change teaching in school, it has to provide sound instructional models based on educational theory that student teachers can operationalize into concrete teaching activities that will work in an actual classroom. These teaching activities need to result at least in similar outcomes as traditional approaches (i.e., level of performance, passing an exam) within the time available. My own experiences so far show that the first step towards an improvement can be done quite successfully. Student teachers realize challenges in teaching when reflecting on experiences they made both as pupils during their own school days and as students at university. However, it seems to be more challenging for the students to operationalize general teaching approaches into meaningful sequences of teaching activities. This might be due to a lack of experiences with such sequences but probably even more to a lack of deep content knowledge and hence a lack of sufficient pedagogical content knowledge. As a consequence, the third step—achieving satisfactory results—is even more challenging. In addition, pupils might resist these approaches fearing lower performance results. This might be a threat to alternative teaching approaches because these need more time in the beginning to produce coherent understanding, which, in the long run, will facilitate further learning.

A coherent science teacher education

An ideal science teacher education requires a close cooperation between all staff and institutions involved as indicated in the PICoSTE model (see Figure 2.1). These include lecturers in the science subjects, in science education, and pedagogy at university and supervising teachers at schools. The science content taught at university is tailored to provide an understanding of central science concepts. Educational courses focus on the teaching of these concepts. This requires collaboration between university and schools to provide examples of current teaching that are analyzed and further developed before teachers and student teachers try out the changed approaches. This collaboration has to continue over time to allow for the establishment of new teaching routines. In addition, improved learning outcomes of the pupils have to be made visible to foster acceptance of new practices in the classroom. The state regulations for teacher education programs formulate such an ideal in its general part. However, mandatory teaching practice in school without yielding credits and economic conditions hindering tailor-made subject courses for student teachers make it difficult to reach such an ideal.

... and what we do at UiB

Teacher education at UiB is organized with widely distributed responsibility. Several faculties are involved which requires a high level of coordination. On the other hand, this structure provides opportunities for actions at the faculty level. In the following, I will present three examples from the faculty of mathematics and science that show how we try to have an impact on coherent science teaching through our program. The first example is about a partnership between the faculty's teacher education program and schools who offer practice placements for student teachers. The second is about a complex teaching-learning approach (Ambitious Science Teaching, AST) with a potential for increased science understanding that was introduced in the chemistry education course. The third is about an R&D project (ARGUMENT) that uses current societal issues with a scientific component to foster critical thinking and argumentation in lower secondary school.

Collaboration between schools and university in science and mathematics

Developing collaboration between university and schools is an important part of supporting coherence in science teacher education (see Chapter 2). Through this collaboration, student teachers are provided with examples of coherent science teaching (implemented coherent curriculum) and with opportunities to practice their own ideas based on what they have learned at university.

Students in the teacher education program have two periods of 6-9 weeks where they are practicing teaching in schools. They are working together with a fellow student in one of their subjects and alone in the second. After about two weeks, during which student teachers mainly observe their supervising teachers' instruction in class, they usually take over responsibility for the teaching in the following weeks. Twice during each period, staff from the university observes a lesson given by the student teachers, which is subsequently discussed.

The initial aim of the collaboration between university and schools was to secure enough places for our student teachers and improve the outcomes of the program. Schools have to apply to participate and explain what their special focus in science and mathematics is. In the first round, five schools each from lower and upper secondary level were selected. Later, due to a rise in student teacher numbers, more schools were taken in. Schools agreed to take at least five student teachers per year. The faculty invites teachers from the collaborating schools two times per semester for a half-day meeting. At these meetings, topics spanning from administrative issues concerning the practice placement of student teachers over current school-related developments to how science educators make use of student teachers’ experiences from practice are discussed.

Through the collaboration, a closer contact between staff from schools and university has been established, and there is a growing understanding of what the respective partner is doing. The supervising teachers are more aware of assignments related to university courses that the student teachers bring to the practice, and the students get better support to fulfill them. Especially in cases where teachers supervised student teachers over several years, I realized that the teachers became more open towards students trying out new approaches. Despite many positive results of the collaboration, there are areas where it is difficult to achieve improvements. For example, all actions that require a direct collaboration between teachers and university staff are limited due to a lack of resources and thus a lack of time.

The collaboration in science and mathematics had, however, a second aim: the selection of so called university schools that would become part of a more privileged relation. UiB has established such a status but regards these schools mainly as recruiting areas for new students.

Comparing our university schools with the university school we saw in Helsinki and the practice school in Copenhagen makes possible improvements of the different systems visible. The UiB system could benefit from a stronger continuity regarding practice, placement, and supervision. In the current system at UiB, schools decide every year how many student teachers they can accommodate and who will be the supervising teachers. Also, a reduction of the number of teaching hours in the responsibility of the student teachers would leave more time for elaborate planning and reflection. On the other hand, placing two student teachers together in one subject, as practiced at UiB, gives the student teachers the opportunity to experience co-teaching and benefit from the different perspectives they bring to the class.

Introducing powerful teaching approaches in university courses

Powerful teaching approaches provide tools for student teachers to plan and design teaching sequences that support deep learning. They support using the reflective dynamo in the PI-CoSTE model (Figure 2.1) and connect university and school context.

In recent years, I introduced inquiry approaches to my student teachers in chemistry education because they are supposed to support a deeper understanding of science (Furtak et al., 2012; Minner, Levy, & Century, 2010). The student teachers appreciated the approaches for engaging pupils but were critical concerning time used and learning outcomes. In addition, I felt that the introduction did not provide them with enough knowledge and skills to develop their own inquiry lessons. When I visited my student teachers during their school practice, I observed only few lessons that incorporated elements of inquiry. Recently, I have added Ambitious Science Teaching (AST) as an approach that is in contrast to the idea of open inquiry, which is still seen as beneficial compared to recipe-style experiments. AST has a clear structure based on year-long research and provides descriptions of the core teaching practices and available research evidence. It also offers tools that can be used to put AST into practice alongside examples documented by classroom videos (Windschitl, Thompson, & Braaten, 2018; Windschitl, Thompson, Braaten, & Stroupe, 2012). The four core practices are: (1) planning for engagement with important science ideas, (2) eliciting students' ideas, (3) supporting on-going changes in students' thinking, and (4) pressing for evidence-based explanations. These practices are not new but combined and elaborated in a convincing way.The core practices in AST contribute to a coherent teaching. The first practice identifies important scientific ideas to be learned (intended coherent curriculum) and connects them to a phenomenon (anchoring event) and a sequence of teaching-learning activities. The provided planning tool requires the student teacher to construct a causal explanation of the anchoring event and to identify what pupils are supposed to have understood after the sequence. This practice has similar features as the CoRe (Content Representation) that we encountered during our visit to Halmstad (Hume & Berry, 2011). The second practice makes sure that pupils' ideas are appreciated and used as a starting point. These ideas are used to adapt further teaching. The third practice entails that pupils can gradually refine their thinking about the anchoring event by testing conjectures and integrating new information and concepts. The fourth practice presses pupils to use evidence in their explanations and to learn to critique and defend explanations.

After introducing AST in my course, the student teachers still react to the new approach in a similar way as to the earlier ones. They find it especially difficult to identify relevant science ideas and a suitable anchoring event. They often think of topics (i.e., acids and bases or chemical bonds) instead of scientific ideas (i.e., acids and bases each have a certain property that is neutralized if an acid is mixed with a base). A second difficulty is that AST proposes core practices, which have to be practiced in order to learn them. University courses, however, are limited in providing opportunities to achieve this.

A step towards a better learning of AST was tried during the PICoSTE seminar in Bergen. Towards the end of the course, the student teachers were given an assignment to come up with ideas for science concepts that can be used for inquiry approaches. Many student teachers produced useful ideas. Some of the ideas (dancing raisins in carbonated water, Landolt reaction, color of an acid-base indicator in different household chemicals, and combustion of a candle) were discussed by the student teachers in groups. They identified what could be observed in the different demonstrations and how pupils might explain the observations. Regarding the dancing raisins, the student teachers suggested that pupils might believe that all raisins will dance in the glass, that water is going inside the raisins, or that the bubbles forming on the surface of the raisins might make them rise to the surface of the water. In a follow-up discussion, the groups suggested further experiments to confirm or challenge pupils' ideas. The group with the dancing raisins suggested comparing carbonated water to tap water or to use nuts or peas instead of raisins. The session helped my student teachers to focus on an observable phenomenon and suggest reasonable explanatory ideas that could be used to design inquiry activities.

Inspired by our visit to the digital learning lab in Halmstad, I introduced a session where student teachers work with data logging equipment in a school laboratory. Some of the experiments were adopted by student teachers when they had their school practice. In the next course, I want to combine the two ideas to work more in line with the AST approach using a relevant topic from the curriculum. This idea is also inspired by the lesson about the 6E-model (a Danish version of the BSCS 5E-model (Bybee, et al., 2006)) that we saw in the PICoSTE partner visit in Copenhagen.

Making teaching at university fruitful for coherent science teaching in school requires not only that student teachers learn about instructional models but also that they try to enact them both at university and in school. Knowing how something works is a necessary precondition, but making it work needs a practical approach and some training.

R&D to improve critical thinking and argumentation in science

Bergen municipality as the owner of the lower secondary schools, Bergen University College (HVL), and UiB were awarded a grant for an innovation project (ARGUMENT, 2018-2022). The main idea is to use current societal controversies with a scientific component to foster argumentation and critical thinking in lower secondary pupils. Together with three local schools, engaging topics were identified and teaching sequences of around 20 lessons were developed and implemented. The projects are about climate change (Does it rain more in Bergen now than in earlier times?), sustainability (Is it beneficial for climate and health to eat vegetarian?), and energy (Is it worthwhile to install solar panels in Bergen?). The schools get support for finding appropriate data from open databases (i.e., yearly rainfall over 100 years for the rain project) or produce their own data (i.e., measure rain or electricity produced by solar panels). The pupils are supposed to analyze the data and compare their results with those of others to find evidence-based answers to the controversy. By providing engaging and relevant real world issues, we hope that pupils will realize the complexity in these issues and feel the need for more scientific knowledge. They should acknowledge that claims usually must be supported by quantitative evidence, illuminating the power of mathematical models.

The municipality intends to spread the materials produced and the experiences gained to all the other schools as part of their quality development. It is also regarded as a good opportunity to support the implementation of the new curricula that stress critical thinking, inquiry, and argumentation. Teacher education at UiB can benefit in two ways from the R&D collaboration. First, master's students from the teacher education program can be involved in the project to learn more about developing and implementing instruction aimed at fostering competencies needed in the future. Second, as more and more schools adopt materials and ideas from ARGUMENT, teaching practice for student teachers may become more in line with the teaching at university and the student teachers get a proper training in setting up engaging and challenging science teaching.

Aligning arenas in science teacher education

The examples show how we try to further align different parts in the science teacher education program at UiB as depicted in the PICoSTE model. We aim to improve the coherence between subject and subject education studies as well as school practice. Tools for this are a better collaboration between university and schools, the introduction of powerful science teaching approaches, and a research-based improvement of the teaching of critical curricular topics in collaboration with the school authorities.

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5. Enhancing Coherence by Embedding Science Teacher Education in the Context of Initial Teaching Practice

University of Copenhagen, Denmark

In Denmark, pupils are educated in science subjects in the mandatory primary and lower secondary school system (Folkeskolen/Grundskolen) from the age of 7 to 15, and further at the upper secondary school level (Gymnasium), typically from the age of 16 to 19. The Gymnasium is divided into four types (STX, HTX, HHX & HF)[1], with science subjects being a part of the education at all types except the HHX schools. The system is summarized in Table 5.1.

Normally, only teachers at the Gymnasium level have university degrees in the subjects they teach whereas lower grade teachers have a broad sample of science course work.

Brief overview of the Danish context for science teacher education

In Denmark, science teacher education at the upper secondary level coincides with an initial year or during the second year of teaching in a secondary school. Before beginning teaching,

Table 5.1: Overview of science subjects taught in the Danish school system.

Age (grade)	Science Education
Folkeskole (primary + lower secondary) – mandatory	
7 - 12 (1 - 6)	Natural sciences/technology: A combination of science subjects. Students are taught basic scientific concepts and principles, typically in relation to their everyday lives.
13 - 16 (7 - 9)	Physics / Chemistry: A combined subject at this level. Geography Biology
Gymnasium (upper secondary)	
16 - 19 (1 - 3)	Combined science courses: Some of the schools in the Gymnasium system offer combined science courses. Physics Chemistry Biology Physical geography

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[1] The STX (The Higher General Examination Programme) is the more general of the four, which most students attend; the HTX (The Higher Technical Examination Programme) has an added focus on science and technology; the HHX (The Higher Commercial Examination Programme) focuses on business and economics and the HF (The Higher Preparatory Examination) is a two-year programme. More detailed information can be found at the Ministry of Education website (http://eng.uvm.dk/upper-secondary-education/national-upper-secondary-education-programmes).

most university science students major in two science subjects over a five-year course of study, concluding with a master's degree. Then, prior to any teacher education, they apply for and if accepted, begin teaching at an upper secondary school.

During their first or typically their second year of teaching, they participate in a part-time course in teacher education (the Pædagogikum) supported by mentors in their schools.

Typically, during this program, they teach half-time and during the rest of the time, attend courses with other new teachers from other upper secondary schools, who are also in the Pædagogikum. These courses are of two kinds: theoretical and practical. There are three theoretical modules which include one in general pedagogy and the other two are specific to teaching and learning in each of the new teacher's two specific content areas, such as, biology and physics education. The practical part is the half-time teaching under the guidance of a mentor at the upper secondary school where the new teachers are employed. Typically, they will share at least one class with the mentor where they gain supervised experience. They conclude their pedagogical year with a thesis and then are fully certified to continue teaching, often at the same school where they have been teaching.

Teacher education aimed at primary teaching is substantially different. It is a four-year program at special schools called University Colleges (not associated with any Danish university). The pre-service teachers complete a program leading to a professional bachelor's degree in education, with three elected subjects such as four science subjects, Danish language or history. Supervised practice is part of the four-year bachelor's program. The pre-service teachers are then qualified to teach from Grade 1 to Grade 9.

In Denmark, there are three advantages in securing a teaching position before engaging in teacher education:

1. This experience based integrated teacher preparation is meant to take advantage of constructivist learning theories which include emphases on experiential learning in situ.
2. University students and hence future teachers maintain their identity as a master of their subject area, for example physics, rather than adopting that of a teacher while at university. In Denmark, this is considered an important separation of science and pedagogy useful in attracting highly qualified science students to teaching. Rather than relinquishing their science identity for that of a teacher while still at the university, they enter upper secondary schools teaching as a scientist and then learn in that environment the relevant pedagogy they need for successful teaching and learning. This advantage is weighed against the extensive pre-teaching preparation which is common in many other countries.
3. Since in Denmark, students rarely know that they want to become teachers when they begin university studies, waiting until after they finish five years of university studies for them to decide on teaching eliminates the need for earlier decisions. When such early decisions are required, student scientists may not choose a path to teaching since an early choice may block other science career paths.

However, there is also some interest in providing more pedagogical orientation to new secondary science teachers before they begin teaching. An early effort at the University of Copenhagen are two courses offered by the Department of Science Education to help prepare students for beginning to learn to teach at an upper secondary school. These courses are chosen at the end of the five-year science content mastery by students who want a little guidance for their first teaching experiences. One course provides a theoretical basis for learning and teaching and the other is practical and helps them apply that basis in planning and executing teaching.

Practices in the Danish system that support coherence

Affordances of the optional pre-service University of Copenhagen (UCPH) programme in promoting coherence of teaching and learning.

Those who enroll in the UCPH courses learn and use a template of inquiry-based science teaching which has been derived from the original 5E template (Bybee, 2015) that included a cycle with this sequence of phases: engagement, exploration, explanation, elaboration, and evaluation and was later modified by Eisenkraft (2003) with the addition of an elicit phase before the exploration. The resulting template used in the UCPH education courses includes these phases with a substitution of feedback for evaluation. This six-phase template is conceptualized with the graphic in Figure 5.1. Theoretically, this template adopts a constructivist perspective in that participants build their own understanding through experience, reflection, and discussion (see for example Tobin, 2012). This approach differs significantly from traditional teaching where students read or are told science before engaging in a laboratory experience where they confirm what they have been taught.

This constructivist perspective of the UCPH teaching template is coherent with how new teachers also learn about the template. They explore the attributes of the template through many experiences followed by reflections, which lead to deeper understanding and then extensions as they try both planning and executing lessons using the template. There is also coherence between how the UCPH template is taught In the PICoSTE model in that the shared overlapping university and school contexts interact in the central core with experience relevant to schools driving teacher preparation. Through inquiry, it provides university students with a consistent set of planning and reflection tools (see Figure 5.1 for the tools; see Figure 2.1 for where they use them for development and planning) which students then use to plan teaching in the central core of the model before enacting their plans and again process them within the central core.

Using this pathway to inquiry, UCPH students learn to begin science lessons by finding out (eliciting) what pupils know about the current topic and simultaneously arousing pupil interest (engaging). Then, instead of telling them what they need to know, the students learn to create a concrete or virtual place where pupils can examine the phenomenon or content, collect observations and begin to form an understanding of the topic. Such lessons then help pupils bring their observations and initial ideas from the explore phase to a discussion that results in understanding the topic (explain) with guidance and additional information from the teacher. Finally, pupils are challenged to apply their understanding in a new situation (extend). Throughout the lesson, pupils get continuous formative feedback to help them stay connected with the task. Simultaneously, because this course continuously interprets feedback as both to the student and to the teacher, the teachers get continuous feedback about pupil progress so they can adjust the lesson for maximum effectiveness.

This 5E+1F template (see Figure 5.1) is highly coherent with how science is usually conducted in that scientists explore their interests and build explanations as they make observations and collect data. This is an important difference between the 5E+1F inquiry template and more traditional teaching where students learned about completed science from the teacher and/or a textbook before confirming what they were told in a laboratory. Consequently, use of the template has the potential to communicate both the challenges and rewards of doing science. Using the template is also coherent with some school programs in Denmark where inquiry-based teaching in science is common and where the Pædagogikum (see next section) also supports the basic tenets of inquiry teaching and learning. However, in other schools and in some versions of the Pædagogikum, the UCPH template is not coherent, resulting either in reflection inducing dissonance or frustration at not finding their UCPH courses useful. This happens when UCPH students, who have been prepared for inquiry teaching, don't find this pedagogy in their first teaching school.

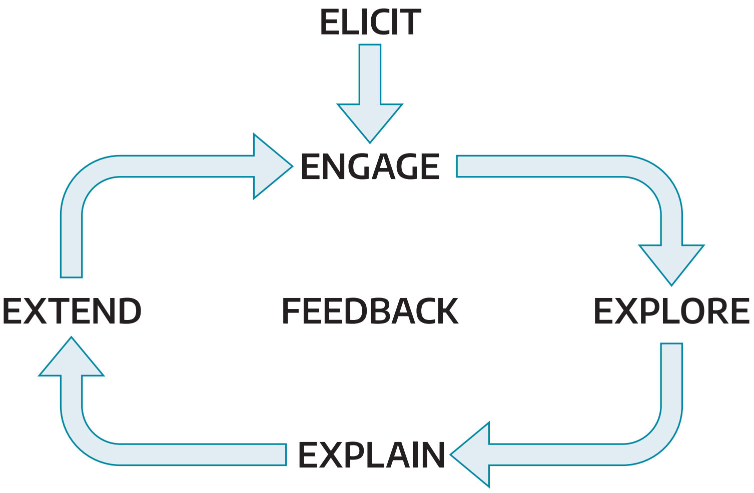

Figure 5.1. The inquiry template used at the Department of Science Education, University of Copenhagen for science teachers. Four of the original '5Es' (Bybee, et al., 2016) of engage, explore, explain, and extend are retained here; elicit is added and feedback replaces evaluation, resulting in a 5E+1F template.

During the University of Copenhagen program, students use this inquiry template to teach lessons in upper secondary schools with peer, instructor and local teacher feedback. They plan lessons for science classes in alignment with learning objectives provided by classroom teachers using the inquiry-based strategies from the UCPH courses. Their lessons are observed by the classroom teacher as well as by other members of their UCPH class with subsequent written feedback from both the pupils and peers as well as a discussion with the teacher about their experience. They revise these lesson plans for coherence, based on the three sources of feedback and submit their final plans to the UCPH course faculty for assessment.

The simple and easily recalled summary in Figure 5.1 helps promote two kinds of coherence. By integrating all the components sequentially in this figure, students can easily assure for themselves that they are developing lessons and teaching in full concordance with the constructivist inquiry theory that is the basis for this pattern. Furthermore, because the patterns generally capture scientific work in a simplified, yet authentic manner, it increases coherence between the classroom and world of scientific work.

UCPH students further experience the Figure 5.1 model by joining a school science field trip study using inquiry to discovery its affordances and challenges for learning science content and process. For example, the UCPH students have been invited to join a day-long bus trip to a geological site taken by two upper secondary school science teachers along with their pupils. During this trip the university students were both teaching participants, helping students collect and make sense of data by asking questions and supplying feedback, as well as teaching/learning observers. They noted the differing orientation of the two teachers to their respective classes and the consequent success of the students. As observers, they were able to finely note what tasks were motivating for the students, which were doable and which were not. Afterwards, they analyzed their observations and suggested a plan for such a field trip using both the successful elements of the one they experienced as well as making changes based on their experience, completing the central core of the Figure 5.1 template.

The final exam for the second of the two UCPH pre-service secondary school science teaching courses is given in upper secondary school classrooms with pupils. It emphasizes coherence between the university and schools since pre-service students must align their methods to the context of a school classroom and curriculum. Even though it is one of several times when students teach lessons in the schools, introducing the goal of the exam from the beginning of the course provides a coherent goal for the entire course by emphasizing the need for relevance to reality in everything else done in the course. All of the UCPH students taking the exam observe one another both to prepare for the oral examination at the end of the day where they are not only asked to reflect upon their own teaching exam experience but also on that of others, as in the central core of the PICoSTE model. Issues of coherence between their experience in an authentic teaching situation and preparation using teaching methods from their university classes, are constant parts of their exam reflections.

Approximately one-third of the advanced course students complete their master's thesis in science teaching and learning, usually with data collection in schools. For example, for his project, a recent graduate surveyed former students of the UCPH program who were full-time teachers about their ability to implement what they learned at the University in their teaching (Holm, 2018). In interviews, he found that the new Danish teachers felt the inquiry template on which the UCPH course is based was "... a valuable pedagogical tool that they frequently implement in their teaching." He also noted that many variables in schools and teaching such as time constraints and the ability to provide sufficient feedback, reduce the coherence of strategies learned at the university, and consequently, these new teachers needed to modify the taught coherence from the university to fit what they experienced in their classrooms (see central core of the PICoSTE model, Figure 2.1). Notably, they kept the inquiry structures they learned, using at least part of them in for each lesson when they were unable to fully utilize an overall inquiry plan (Holm, 2018). Holm's study recommends further coherence between university courses and schooling by specifically including strategies for handling realistic class times and accommodation of extended feedback.

Role of the one-year learning to teach (Pædagogikum) program in promoting coherence.

During the one-year of teacher education (Pædagogikum), Danish student teachers are employed at their local secondary schools, planning and teaching a large number (hundreds) of practical lessons, both on their own and when supervised by a mentor. This facilitates a high level of coherence between what they are taught and realities of the actual school context because the mentor interacts with the new teacher about lesson plans, outcomes of teaching and opportunities for co-teaching. The simultaneous weekly teaching responsibilities and program work continuously raises issues of coherence between what is being taught and what fits the classroom, resulting in reflection and discussion.

The constructivist theoretical basis for the program posits that rather than modelling the older transmissive form of teacher education where students are immersed in coursework before they have significant school experience, the Danish system for science teacher preparation models the methods of inquiry-based science teaching that first immerses students in teaching experiences. It then helps them, through the mentors and the Pædagogikum to construct an understanding of constructivist teaching practices based on their teaching experiences.

Furthermore, during the Pædagogikum, new teachers simultaneously engage in theoretical courses and practical teaching experiences. This allows them to try out what they learn in the theoretical part of the program in an entirely authentic context, and to reflect on their experiences back at the theoretical courses. This facilitates authentic real-time coherence as well as in-coherence between the theoretical and practical parts of the program.

Subsequent support for coherence in teacher preparation.

During the Pædagogikum, support continues through Ministry initiated in-service teacher workshops, which frequently reinforce non-transmissive teaching, coherence with both the UCPH courses and the Pædagogikum is enhanced. Support is also provided through national conferences, Danish journals and meetings with in-service teachers where alignment and coherence is enhanced for both the Department of Science Education and teachers.

Coherence is enhanced due to Danish National Ministry of Education employees and practicing Danish teachers serving as censors for masters' projects conducted by pre-service science teachers. In addition, the Danish science education journal and yearly country-wide science education conference organized by the Department of Science Education, enhances communication and coherence. The Department of Science Education also promotes assessment strategies at the national level that also promote non-traditional forms of teaching. The goal is to align national assessment practices with the inquiry-based teaching offered by the Department and Pædagogikum work.

Synergistic coherence in science teacher preparation

Because some new science teachers coming from the UCPH will experience both the two university pedagogy courses and the required Pædagogikum sometime during their first two years of teaching, there are places where they encounter non-coherence with the reality of their daily teaching. Of course, some lack of coherence is positive in that it creates disequilibrium which requires them to reflect and consider different perspectives based on the actual experiences they are having as new teachers. They must find coherence or lack thereof between their two pedagogical experiences, which is consistent with our constructivist vision for science teacher preparation.

Even though the Pædagogikum is intended for the first year of teaching science, in practice, student teachers are often not enrolled in the Pædagogikum during their first year of teaching, but rather after they have had some practical experience with teaching. From a constructivist perspective, this means that student teachers typically have a good grasp of school realities and a lot of personal experience with teaching when they are presented with theories of pedagogy and models of teaching, which forces the theoretical courses to align coherently with the school context. This means that pedagogical instruction must encourage coherence in science teaching since these student teachers can daily identify how incoherence in their lessons reduces success for their students. When students already know from first-hand experience about the opportunities and challenges of teaching, they bring experiential coherence to their lessons.

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6. Linking Facets of Teacher Knowledge and Connecting Different Phases in Science Teacher Education

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In Germany, science education in schools is obligatory. Each student should develop competences in biology, chemistry, and physics. These three disciplines are mainly taught as separate subjects, but sometimes also as one subject called integrated sciences. The Standing Conference of the Ministers of Education and Cultural Affairs of the Länder in the Federal Republic of Germany defined the respective competences as national educational standards (Sekretariat der Ständigen Konferenz der Kultusminister der Länder in der Bundesrepublik Deutschland [Hrsg.], 2005). For example, the educational standards in chemistry are organized by four competence areas that are: (1) conceptual knowledge, (2) scientific inquiry, (3) communication, and (4) socio scientific issues. At present, they are only valid for the leaving certificate at the end of the secondary level I (grade 5 to 9 or grade 5 to 10). But, standards for the secondary level II (grade 10 to 12 or 11 to 13) are under development and will be published within the next few years. A nationwide large-scale assessment monitors whether or not students' actual competences meet the standards.

A few decades ago, PISA 2000 revealed that German students' competences in science were less developed than in many other OECD countries (Baumert et al., 2003). German students performed significantly below average. For example, it became obvious that compared to the student populations from other OECD countries a relatively high number of German students did not reach the first competence level. The main reason for this finding was the social background of the students and their linguistic competence that both are predictors for students' scientific literacy. Since then, the situation has changed and in PISA 2015 German students performed significantly better than the average of all participating students from the OECD countries (Schiepe-Tiska, Rönnebeck et al., 2016).

Regarding the way of teaching and learning science, there are two main principles that were described as being effective for science learning in the German context: (1) problem-based learning and (2) context-based learning (i.e., Nentwig, Demuth, Parchmann, Gräsel, & Ralle, 2007; Schmidkunz & Lindemann, 1992). Empirical findings confirm the assumptions that both principles support learning science. However, when looking at class teaching it is not clear if these principles are commonly used for teaching and learning science. The few existing insights suggest that doing experiments to solve problems and using contexts to increase students' interest is not common and sometimes poorly realized; for example, German students plan experiments on their own significantly less often than the students of that survey on average do (Schiepe-Tiska, Schmidtner et al., 2016). It is assumed that teachers' beliefs play a central role when looking for possible reasons. This is why there is a focus in teacher education programs on implementing experiments and contexts in science class.

Based on the research that was done in the context of the COACTIV project (Cognitiv Activation in the Classroom: The Orchestration of Learning Opportunities for the Enhancement of Insightful Learning in Mathematics) and, consequently, in the field of mathematics education a vivid debate was started about the aims and the quality of teacher education programs in general. In a first phase, the debate focused on the structure of teachers' professional competence and on the content of teacher education programs (Borowski et al., 2010). In a second phase, the focus of the debate was shifted to the quality of teacher education programs as well as on the learning processes that might best support the development of teachers' professional competence (i.e., Kleickmann & Hardy, 2019). The two examples of practices that support coherence described below can be seen in this light. In both examples, specific facets of teachers' professional competence should be supported by a certain methodological approach. A short summary of the German context of science teacher education is provided before each example.

Brief overview of the German context of science teacher education

In Germany, science teacher education is organized in two phases. The first phase is the university-based teacher preparation program that takes three years for the bachelor's program and two years for the master's program. It ends with a master's degree that qualifies prospective teachers for the second phase. At the university, pre-service teachers have courses in educational sciences, in two subjects, and the respective subject educations. The idea behind this tripartite structure is that the professional competence pre-service teachers need includes pedagogical knowledge (PK), content knowledge (CK), and pedagogical content knowledge (PCK). In contrast to some other countries, these areas of teachers' professional competence are taught separately because of the tripartite structure of the courses. In addition, the students have practical studies at schools in order to apply their knowledge in authentic teaching and learning situations. The second phase, the Referendariat, is an in-service teacher training program that takes one and a half years. In this phase, the beginning teachers teach a relatively small number of lessons at school, while simultaneously attending courses at a study seminar, the Studienseminar. At the end of the second phase, the beginning teachers receive their state exam that formally qualifies them as (science) teachers.

Science teacher education in Germany is also divided into different tracks that qualify the prospective teachers to teach at different school types. In general, there is one track for students becoming teachers at primary schools, one for those who become teachers at lower secondary schools, one for those who will teach at upper secondary schools, and a fourth for those who will teach at vocational training schools. For these four tracks, there are separate courses at the universities and the study seminars, especially in subject education. This structure mostly represents the current state of teacher education programs in Germany. However, one has to consider that in Germany there is not one single teacher preparation system, but 16 slightly different ones. Germany is a federation of 16 federal Länder. Throughout history, the territories of the Länder have retained independence from the federal government with regard to educational affairs. Today, the Länder still have cultural sovereignty, which leads to the fact that Germany has 16 similar but slightly different teacher preparation systems.

The variation in different science teacher education programs is indeed even greater in that the 16 teacher preparation systems are adapted to the specific conditions of the regions in the Länder and to the conditions of single universities. (for about German teacher education see Neumann, Härtig, Harms, & Parchmann, 2017)

Description of two practices that support coherence

Given the described background regarding science teacher education in Germany, there are two aspects that seem to be important for the development of pre-service teachers' professional competences. The first aspect is linking content and pedagogical content knowledge (PCK), and the second aspect is linking the first and the second phase of science teacher education. Both aspects are relevant because of the organization of science teacher education programs in Germany. The question is: With which methods can prospective teachers best develop their professional competences under the given conditions? The first methodological approach is an explicit link between content knowledge and pedagogical content knowledge by conceptual strand maps that highlight the importance of teachers' content knowledge for teaching. The second methodological approach is an implicit link between the first and second phase of teacher education by focusing on the improvement of multiple external representations in teaching and learning materials. Both approaches and their connection to coherence in science teacher education will be explained in the following sections.

Linking content and pedagogical content knowledge.

The first approach is linked to the framework for promoting coherence in science instruction via the university context and the focus on the intended coherent science curriculum in pre-service teachers' coursework. The core idea for coherent science instruction is the coherent development of scientific concepts across school years that can be supported by conceptual strand maps.

What is actually done?

The aim of the approach is to increase the perceived relevance of the content taught in university courses for becoming a teacher. In methodological terms, this is to be achieved by making knowledge at the university level and knowledge of the school level, as well as the horizontal and vertical links of this knowledge, explicit. In concrete terms, this means that pre-service teachers should experience their content knowledge learned at university as useful for content-related activities in their profession, such as the planning, implementation, and reflection of teaching and learning. Pre-service teachers should thus be given the opportunity, within the framework of previously purely subject-related courses, to directly combine content knowledge at the university level with questions relevant to teaching and thus link content knowledge and pedagogical content knowledge accordingly. As a first trial, a module from physical chemistry was chosen for the implementation of the approach, in which a focus was placed on chemical thermodynamics. Experience has shown that it is particularly difficult for prospective teachers to make connections to school chemistry and thus to their future profession for this topic.

The three two-hour lessons referred back to the content already covered in the related lecture about physical chemistry and focused on different aspects of structuring content knowledge. The topics covered are physical states and their transitions, the energetics of chemical reactions, and entropy. By choosing these topics, pre-service teachers should be supported in recognizing the relevance of content knowledge at the university level, both in the case of rather obvious links with chemistry teaching and in the case of references that are not directly visible. For example, on the basis of the topic states of aggregation, the students are confronted with a typical content from the initial chemistry lesson. This topic is treated at a relatively low level of abstraction in the school subject and has a relation to numerous phenomena in nature and in everyday life, but which is conveyed in much greater detail and complexity in the lecture, especially from the point of molecular interactions. In this way, students will experience the relevance of this detailed and in-depth knowledge of the topic of states of aggregation for chemistry lessons. Therefore, it is a topic which at first sight seems to be very relevant to school, but which shows a large discrepancy between the knowledge at the university and school level when looking at concrete contents or topics.

Each of the three lessons followed a similar sequence. Since the aim of the approach is to make the networking between content knowledge at the university and the school level explicit, the seminar is framed by the use of conceptual strand maps as representations of the respective knowledge structures. At the beginning of each lesson, the knowledge at the university level associated with the respective content is structured in the form of the mentioned maps. The contents of the lessons can be used to successively add links to the knowledge at the university level. In this way, the aspects of knowledge at the school level are to be covered; for example, in addition to the logical connections and sequences of contents, the assignment of contents to the basic concepts is also addressed. At the end of each lesson, the prospective teachers reflected on the perceived connections and the perceived relevance of the content knowledge at the university level for subject-related teaching activities in school.

Why is it done?

In the first phase of German teacher education programs, there are university courses that can be assigned to the important areas of professional knowledge: (1) pedagogical knowledge, (2) content knowledge, and (3) pedagogical content knowledge. This means that in Germany university courses usually have a strong focus on one of these areas of professional competence and do not link these areas explicitly. This can be seen as an aspect of the university context where the coherence of teacher education programs is not given (Kleickmann & Hardy, 2019). The assumption is that this situation might have a negative effect on pre-service teachers' perceived relevance of the content knowledge they learn in the first phase. Surveys that asked for pre-service teachers' perceptions support this assumption (Blömeke, Müller, & Felbrich, 2006). Therefore, it should be an aim for the first phase of teacher education to link the mentioned areas in university courses, especially if the studies at university follow the described structure (Kleickmann & Hardy, 2019). At some universities, within the first few semesters students attend courses that only address pedagogical and content knowledge (Bauer, Diercks, Rösler, Möller, & Prenzel, 2012). Especially here, it seems crucial to implement a link to pedagogical content knowledge in order to increase the perceived relevance of the taught content knowledge.

The often-low perceived relevance of the content knowledge taught might lead to difficulties for the pre-service teachers to teach the respective science content. Theories of professional knowledge suggest that content knowledge is of particular importance in the education of teachers, since content knowledge is the knowledge base on which pedagogical content knowledge can develop (Baumert & Kunter, 2006). So far, however, there is no consensus as to the width and depth of the expertise teachers must have in order to teach successfully (discussed for mathematics education; Dreher, Lindmeier, Heinze, & Niemand, 2018). In addition, university courses are often not specifically designed for prospective teachers, but rather polyvalent. This can lead to learning situations in which the level and selection of the contents are not suitable for the expertise of prospective teachers. In the case of a strongly pronounced discrepancy between content taught at university and the content taught at school, the problem arises that pre-service teachers might not see the usefulness of studying certain contents for their qualification as a science teacher. The missing or not perceived professional relevance of the subject-related study contents can potentially lead to negative effects in the learning motivation of pre-service teachers (Blömeke et al., 2006). The mentioned discrepancy, or discontinuity, concerns all mathematical and science subjects (Deng, 2007), since not only the quantity, but also the degree of abstraction of the subject content in the transition from school to university is relatively high.

How does this align with coherence?

The presented approach is strongly aligned with the concept of coherence as defined within the PICoSTE project. One part of the developed model (See Figure 2.1) that summarizes recent research on coherence focuses on the university context which is definitely the core of this approach. The university coursework is a possibility to introduce basics of an intended coherent science curriculum. The approach is an example that highlights this idea of a coherent curriculum by using conceptual strand maps. These maps help pre-service teachers to reflect on their knowledge that they have learned at university and that they might need to prepare learning situations for the school context. They might also help them as a starting point for the development of pedagogical content knowledge as the development of a scientific concept might be hindered by students' misconceptions. So, there is a strong relation between content knowledge and pedagogical content knowledge that becomes especially relevant in the school context.

Box 6.1. Project that investigates the effect of linking content and pedagogical content knowledge on the perceived relevance:

Funding Agency:
Kiel University

Program:
Initiative of the presidium of Kiel University

Project Title:
Improving the perceived relevance of academic content knowledge by linking content knowledge and pedagogical content knowledge

Investigator:
Mathias Ropohl (University of Duisburg-Essen),
Mirjam Steffensky (IPN),
Gernot Friedrichs (Kiel University)

Project Runtime:
3 years, Sept. 2015 - Aug. 2018

Publications in German:

Lorentzen, J., Friedrichs, G., Ropohl, M. & Steffensky, M. (2019). Förderung der wahrgenommenen Relevanz von fachlichen Studieninhalten: Evaluation einer Intervention im Lehramtsstudium Chemie. Unterrichtswissenschaft. Advance Online Publication. DOI 10.1007/s42010-018-00036-1

Lorentzen, J., Friedrichs, G., Ropohl, M. & Steffensky, M. (2018). Der vernetzte Aufbau von universitärem und schulischem Fachwissen im Lehramtsstudium Chemie. Entwicklung eines theoriebasierten Lernangebots für die Physikalische Chemie. In: B. Brouër, A. Burda-Zoyke, J. Kilian & I. Petersen (Hrsg.), Vernetzung in der Lehrerinnen- und Lehrerbildung, Ansätze, Methoden und erste Befunde aus dem LeaP-Projekt an der Christian-Albrechts-Universität zu Kiel (pp. 37-50). Münster: Waxmann.

Linking first and second phase of science teacher education through formative feedback.

The second approach is linked to the framework for promoting coherence in science instruction via the school context and the focus on teaching practice. The core idea for coherent science instruction would be the use of multiple external representations that represent scientific concepts in teaching and learning materials in a coherent way. All pre-service teachers should have pre-knowledge in that field, as it is a common topic of science education courses at universities. However, empirical findings show that they do not adequately apply the knowledge. Thus, this topic should also be picked up in the second phase of teacher education.

What is actually done?

The approach is structured in the following way: First, pre-service teachers get an introduction into the topic of multiple external representations by summarizing the state of the art of empirical research. The introduction is tripartite with a different perspective for each part: one from cognitive psychology, one from science education, and one from natural sciences. Each introduction is followed by meaningful activities (i.e., the pre-service teachers edit a given worksheet of poor quality.) The pre-service teachers have to apply their knowledge from cognitive psychology, from science education, and from the natural science to optimize the learning material and shift its coherence. One prominent example are the three levels representations can contain, but that have to be differentiated from each other in order to prevent the comingle of facts that are only true for each level separately, like substances have a color, but not the particles they are built of.

Finally, the pre-service teachers receive formative feedback that aims at supporting their pedagogical content knowledge in view of the use of scientific representations in learning materials. The whole approach will be implemented in the regular in-service teacher training program, the Referendariat. This is why in this second phase the pre-service teachers have to apply the Professional Knowledge that they have acquired in the first phase.

Why is it done?

Students struggle to develop scientific concepts adequately. Often, they hold strong misconceptions that are difficult to change. One way to overcome students' misconceptions but also to prevent the emergence of them is the use of multiple external representations (Kozma, 2003). No matter whether the phenomenon is the evolution of the species or a chemical reaction, representations are an essential communication tool to deliver knowledge about these phenomena to students. The use of representations in science is not only characterized by high specialized forms but also by the application of several different representations combined in one material (Gilbert & Treagust, 2009). In science, they are usually used to link students' perceptions of scientific phenomena with the submicroscopic world, to give students the possibility to explain a phenomenon with knowledge from the submicroscopic level, and to provide different accesses to scientific phenomena. In order to implement multiple external representations in an effective manner, pre-service teachers need both content knowledge and pedagogical content knowledge. Empirical research revealed that the knowledge they build during first phase of teacher education might be insufficient or the application of this knowledge might be difficult for them (Taskin, Bernholt, & Parchmann, 2017).

Furthermore, teachers' competence to prepare instructional materials is indispensable for teaching science effectively. Nevertheless, the use of representations is rarely part of in-service teacher training programs and should be promoted (McElvany et al., 2009). Based on these findings it is important to support the use of multiple external representations in teaching and learning materials by pre-service teachers in the second phase of teacher education. The way to do this could be formative feedback.

Empirical findings confirm the high potential of feedback for educating and training teachers, especially the combination of externally and internally provided performance feedback (Butler & Winne, 1995; Scheller, Ruhl, & McAfee, 2004). Internal feedback is information that results from the reflection of one's own performance. In contrast, external feedback is information that is provided by someone else. By receiving both forms, it is assumed that pre-service teachers can increase the quality of their self-assessment and self-regulation (Butler & Winne, 1995) such as for designing instructional materials.

How does this align with coherence?

In contrast to the first approach, the second approach mainly focuses on the school context. The assumption is that pre-service teachers have learned the theory about multiple external representations in science during the first phase of the German teacher education system.

The focus during the first phase should be the alignment between the intended coherent science curriculum and the possible representations that fit the concepts in the curriculum.
Then, in the second phase the pre-service teachers need support in using multiple external representations in the school context.

When they start to design their first teaching and learning materials they will make mistakes that might stand in contrast to what they have learned by university coursework.

Box 6.2. Project that investigates the effect of feedback on pre-service teachers professional competence to design teaching and learning materials that encompass multiple external representations

Funding Agency:
German Research Foundation

Project Title:
Effects of feedback on in-service teacher candidates professional competencies in using external representations in science education

Investigator:
Mathias Ropohl (University of Duisburg-Essen),
Julia Schwanewedel (Humboldt-Universität zu Berlin)

Project Runtime:
3 years, Sept. 2018 - Aug. 2021

Publications in German:
Tonyali, B., Ropohl, M. & Schwanewedel, J. (2018). Feedback an Lehramtsanwärterinnen und -anwärter zum Einsatz externer Repräsentationen im naturwissenschaftlichen Unterricht. In C. Maurer (Hrsg.), Naturwissenschaftliche Bildung als Grundlage für berufliche und gesellschaftliche Teilhabe. Gesellschaft für Didaktik der Chemie und Physik (Bd. 39, pp. 803–806). Jahrestagung in Kiel 2018. Universität Regensburg.

Usually, many pre-service teachers do not differentiate between the different levels of representations that are the macroscopic, symbolic, and submicroscopic level.

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7. Reaching Coherence via Collaborative Design

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One primary characteristic of Finnish education policy is the collaborative design of national and local level strategies and programs, like the national teacher education development program, teacher education programs at universities and national and local level curriculum. The planning of strategies, programs, and curriculum typically starts with a review of relevant literature and with recognizing the challenges and needs at the classroom, school, municipality, or national levels. Educational policy documents are planned collaboratively in partnership with relevant partners and stakeholders, such as the Teacher Union, the Ministry of Education and Culture, universities and providers of education, and municipalities and other interest organizations. The general aims are agreed on by consensus and these aims are discussed at the local level, modified, and then implemented in the local context. For example, the science teacher education program is planned in collaboration with the people from the Faculty of Science, Faculty of Education, and teachers from the Teacher Training School. After agreeing on the aims, resources from the state and municipality budgets are made available for the piloting and implementation of the aims.

Coherence in teacher education

It is commonly accepted that a secondary teacher needs subject matter knowledge (SMK), general pedagogical knowledge (GPK), pedagogical content knowledge (PCK) and other domains of teacher knowledge in his/her classroom. In order to support student teachers' acquisition of this knowledge in an initial teacher education program, we not only need theoretically-oriented studies, but also learning from practice. However, it is not easy to argue in general or in detail, what kind of combination of knowledge (competence) a teacher needs and the optimal origins for this knowledge. This is because an international understanding of teacher knowledge depends on the following factors:

- how we understand students' learning and well-being in a classroom
- how we understand teacher professionalism / effectiveness
- how teacher professional learning and teacher collaboration are organized
- how we understand a school as a learning community (school development) and
- how education policy is created and implemented (Leana, 2011).

In different countries, there are variations among these understandings.

In organizing an initial teacher education program different kinds of courses, research-oriented studies and teaching practice are needed. Moreover, there are various university teachers from the department of a specific subject, the Faculty of Education, and mentoring teachers who are teaching courses and supervising teaching practice. These teachers and mentors may or may not understand the big picture of the teacher education program. They may or may not know what topics are studied in other courses or teaching practice. Moreover, they could know something about the pedagogical approaches used in various studies. Research on the coherence in teacher education is now examining how the big picture or core aims are shared among teacher educators and what teacher educators know about content and pedagogy used in other courses (Klette & Hammerness, 2016). According to Garet et al. (2001), teacher learning activities should be planned according to the core aims of the program, be part of a coherent program, and support teacher learning. Luft and Hewson (2014) argued that coherency is the way in which training offers focused learning opportunities related to local contexts.

Klette and Hammerness (2016) summarized the characteristics of a coherent program: Indicators of Vision (explicit vision of good teaching, including the articulation of strategies or teaching approaches, which is understood by the faculty and students); and Indicators of Coherence (the vision of the program informs the opportunities to learn in the program at the Faculty of Science, Faculty of Education and Teacher Training School, field experience). Courses, assignments and teaching practice should communicate similar ideas about teaching and learning and require students to link theory and practice. Especially, during the teaching practice, students should become familiar with the planning of teaching according to national and local curriculum (FNBE, 2014), teaching, learning, and assessment of learning process and outcomes and, moreover, the role of reflection and professional learning in the teaching profession. In the planning, it is important to recognize and support the development of students' conceptual coherence by focusing on core scientific ideas and practices over time and across a range of different instructional contexts (Kali, Linn, & Roseman, 2008). Students and teacher educators should be aware of the vision and aims of the teacher education program and understand and agree with it.

Science education and science teacher education in Finland

One characteristic of Finnish science education in comprehensive schools is that science subjects are taught separately at grade levels 7-9 (student ages 13–15). Biology, chemistry and physics are independent subjects with clear goals, content, and evaluation criteria. Further, geography is partially understood as a science subject because it contains strong natural and physical aspects. Science subjects are taught by teachers who have master's degrees in one of the subjects and at least intermediate level studies (60 ETCS) in every subject they teach. There are two teacher groups; the most common subject combinations are: biology and geography, and mathematics and physics or chemistry. It is important to note that the majority of physics and chemistry teachers have mathematics as their major in university.

In 2013–2014, the Finnish curriculum was renewed. The new curriculum emphasizes core science ideas such as guiding the pupils to "obtain sufficient knowledge on interaction, motion, and electricity needed in further studies" (FNBE, 2014) and science practices such as guiding the pupil to "process, interpret, and present the results of his or her own research and to evaluate them and the entire research process." There are clear aims for learning to ask questions, conduct experiments, process and interpret results, and communicate findings. Further, the new curriculum stresses a feeling of relevance and motivational aspects are explicitly stated, for example, "to encourage and inspire the pupil to study physics."

The secondary teacher education program is a five-year master's program, and students major and minor in the subjects they intend to teach at the Faculty of Science or the Faculty of Bioscience. The secondary teacher students carry out a master's thesis (30 ECTS) in their major. They can choose the topic of the thesis to be either with pedagogical or subject orientation. Bachelor's level courses in the subjects at the department of chemistry, physics, and biology are basically the same for all students despite their intended specialization. Undergraduate courses are rather conventional regarding the implementation of the courses in Finnish universities; lectures are accompanied with exercise classes, and special laboratory courses are included in the physics and chemistry programs. There are some master's level courses tailored especially for the student teachers. Especially, in physics and chemistry, there are specific master's courses for teacher students.

In the pedagogical courses, organized at the Faculty of Education, the main idea is to help students combine pedagogical and educational courses with practice. Separate knowledge domains should be integrated in order to become a solid base for applying knowledge and skills in practice. According to the curriculum, the students should, for example, be aware of the different dimensions of the teaching profession (social, philosophical, psychological, sociological, and historical), be able to reflect on their practice and have the potential for lifelong professional development. The students also produce a pedagogical thesis (10 cp). The underlying assumption is that teachers benefit from research orientation as an approach to continuous professional learning and developmental work including, for example, curriculum work and evaluation processes.

One third of the pedagogical studies consist of teaching practice (20 cp) divided into two parts. The first teaching practice includes both planning the teaching sessions together with other students and teaching in the classroom. The second practice is more independent, and students become familiar with advanced assessment methods. The mentor teachers are professionals in helping the students to plan lessons according to the national level science curriculum (FNBE, 2014) and to reflect on activities. From the point of view of instructional coherence, the national level curriculum (FNBE, 2014) emphasizes the use of disciplinary core explanatory ideas in scientific and engineering practices, like explaining phenomena or designing solutions to problems. This means that science learning should be organized around these disciplinary core explanatory ideas, like motion and forces, energy, engineering design, ecosystems and Earth systems. These core ideas are built and applied across time and themes. Scientific and engineering practices refer to the multiple ways of knowing and doing that scientists and engineers apply when studying the natural world and the design world. The practices are, for example, asking questions, developing and using models, planning and carrying out investigations, designing solutions, and obtaining, evaluating, and communicating information.

Collaborative planning of the teacher education

It is characteristic in Finnish teacher education that universities have a high degree of autonomy in teacher education. There is autonomy at all levels—university, faculty, subject, and the individual teacher educator. For example, there are no national regulations regarding the content of the teacher education. Further, the course contents are described in a very general way. For example, aims in the 10 ETCS course in pedagogical content knowledge states that the "student knows and understand[s] subject-based education as educational discipline and knows topical themes of [science] education research." One leading idea behind this autonomy is the ethos of research-based teacher education. Because there are different research focuses in different universities and faculties, the actual content of the teacher education programs varies. The content of a certain course depends on how university teachers interpret the general goals. Curriculum ensures high autonomy within science education at school and in teacher education at university. Thus, in order to achieve coherence in teacher education, collaboration and the building of common understanding at all levels is needed.

National level collaboration.

In order to make progress in teacher education, the Minister of Education and Culture created a Finnish Teacher Education Forum in 2016 (MEC, 2016). The task of the forum was to collaboratively prepare a development program for teacher education, implement it and evaluate its success. Between the years 2016 and 2018, the Teacher Education Forum ordered a literature review related to teachers' knowledge and teacher education. The literature review introduced the outcomes of research related to: the role of education in a society; teachers' knowledge base and their professional learning; teaching and learning in a heterogeneous classroom; the individual differences of learners; and the design and use of educational innovations, such as education technology (Husu & Toom, 2014).

The development program document presents three strategic competence goals for teachers' pre- and in-service education. These competence goals do not actually include all the possible goals, but they do highlight the direction for the development of teacher education.

According to development program document,

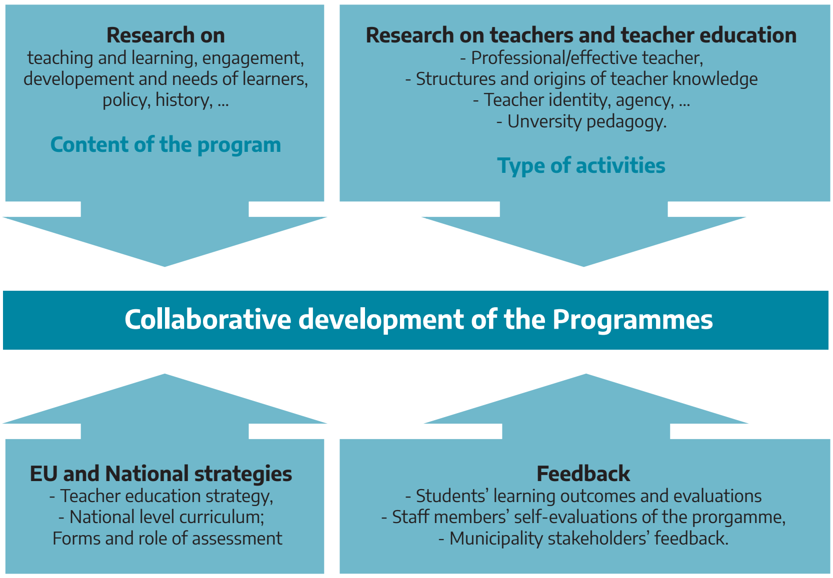
- A professional teacher should have a broad and solid knowledge base, including knowledge about a particular subject and pedagogy, about how to accommodate diversity among learners, about collaboration and interaction, about digital and research skills, about their school's societal and business connections, and about ethics.
- A teacher should be able to generate novel ideas and educational innovation while making the local curriculum, to plan inclusive education initiatives, and to design and adopt pedagogical innovations, including the use of digital tools.
- A teacher should have the competences required for the development of their own and their school's expertise, especially for the development of networks and partnerships with students, parents, and other stakeholders.

Collaboration between faculties and training school.

Science teacher education is organized in several faculties depending on the teaching subjects. In developing the teacher education program, there are representatives from the Faculty of Science, the Faculty of Bio-Science, the Faculty of Educational Sciences, University Teacher Training Schools and municipality schools, and the Student Union.

Partners responsible for science teacher education typically have two meetings during an academic year. The focus of the meetings is outlining a common vision and program for teacher education, discussing development and evaluation of the program, and discussing research and development work dealing with the secondary teacher education (Koponen, Mäntylä, & Lavonen, 2004). The discussion about the core aims of the program is guided by national and university strategies, national level curriculum, research in educational sciences, and student evaluations of the program. For example, during the academic year 2018–2019, the autumn meeting focused on the use of education technology in coherent science teaching. In the beginning of the spring semester, there was an overnight seminar cruise. The seminar started in the afternoon with a presentation of current research and development projects, like the project focusing to coherent science teacher education. During the second day, there were workshops on lesson planning from a project-based learning and instructional coherence perspective.

Figure 7.1. Framework for the designing and implementing the teacher education program at the University of Helsinki.



The overall framework for designing and implementing the teacher education program at the University of Helsinki is presented in Figure 7.1. The aim is that students construct a base of professional knowledge through the courses provided by different faculties and the teaching practice in university training schools. Therefore, co-planning and coordination within the study program are needed to ensure that different domains of teacher knowledge, such as subject matter knowledge, pedagogical content knowledge, and general pedagogical knowledge. Distinctions between these separate domains are discussed in a balanced way during the program. Furthermore, co-operation between university partners and student teachers has also been considered important in the planning and developmental process. The collaborative work not only concerns practical issues regarding the implementation of the teacher education program, it also involves general level visions of the teacher education. For example, the parties involved in chemistry teacher education have agreed on a common vision for the whole teacher education program, including a description of knowledge and skills in the subject matter and pedagogy as well as a description of competence for continuous professional development (also see Lavonen et al., 2007).

The partners in science teacher education have agreed upon the underlying principles of the science teacher education program. Accordingly, the science teacher education program at the University of Helsinki should help student teachers acquire the following:

1. Science knowledge and skills and the competence to use this knowledge (SMK), which includes:
    - an ability to support students in constructing well-organized knowledge structures (expert), which are built on scientific core explanatory ideas, like motion and forces, energy, engineering design, ecosystems and Earth systems.

- an ability to support students in the acquisition of new knowledge through engaging in scientific and engineering practices, like asking questions; developing and using models; planning and carrying out investigations; designing solutions; and obtaining, evaluating, and communicating information, which refers to the multiple ways of knowing and doing that scientists and engineers use to study the natural world and design world.

2. Pedagogical knowledge and skills (edGPK and PCK) including
- an ability to plan, implement, and evaluate learning activities and an ability use curriculum and the skills or competences of the students in the class as a starting point for planning.
- an ability to use formative and summative assessment methods and an ability to guide students to self-assessment.
- an ability to justify pedagogical decisions through psychological, philosophical, historical and sociological knowledge.
- a competence to choose a variety of teaching and motivation methods.
- an ability to use technology in a pedagogically meaningful way.

3. Competence for continuous professional development including
- a readiness to learn new subject and pedagogical knowledge and skills.
- an ability to think reflectively and work collaboratively with colleagues.

In order to better understand the implementation of the program, students are active partners in its development, and feedback is gathered systematically through student questionnaires and discussions about the program. The themes discussed include the quality of teaching, relevance of the pedagogical studies for personal professional development, how well the goals of the program are achieved, and the general study arrangements. In the feedback discussions, student teachers bring up issues that they feel to be essential. Additionally, each teacher educator gathers more detailed feedback about their own teaching according to the personal interest and special characteristics of the course. The evaluation of the program is not only based on student feedback, it is also based on discussions that take place between teacher educators, which is considered an important part of planning the implementation of the pedagogical studies. Student teachers also have an opportunity to take an active role in designing the courses.

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8. Summary and Recommendations

The PICoSTE project focused on the role of science teacher education in promoting coherence in school-based science instruction. Drawing upon the literature describing the features of coherent instruction (e.g., Fortus & Krajcik, 2012; Jin, Mikeska, Hokayem, & Mavronikolas, 2019; Kali, Linn, & Roseman, 2008; Sikorski & Hammer, 2017), we defined coherent instruction as instruction that contextualizes learning around students collaboratively making sense of meaningful and relevant phenomena, focuses on a small set of core science ideas over time, and motivates a perceived need to know about new ideas through carefully constructed learning sequences. Unfortunately, school-based science instruction commonly does not align with these principles for coherence (Banilower et al., 2018; Osborne & Dillon, 2008). Through our collaborative work within the PICoSTE project, we shared specific strategies and developed a broader theoretical model for designing science teacher education that can help resolve the dichotomy between the coherent instruction advocated within the science education research literature and policy documents on the one hand and the more traditional (and less coherent) instruction that is commonly observed in schools on the other hand.

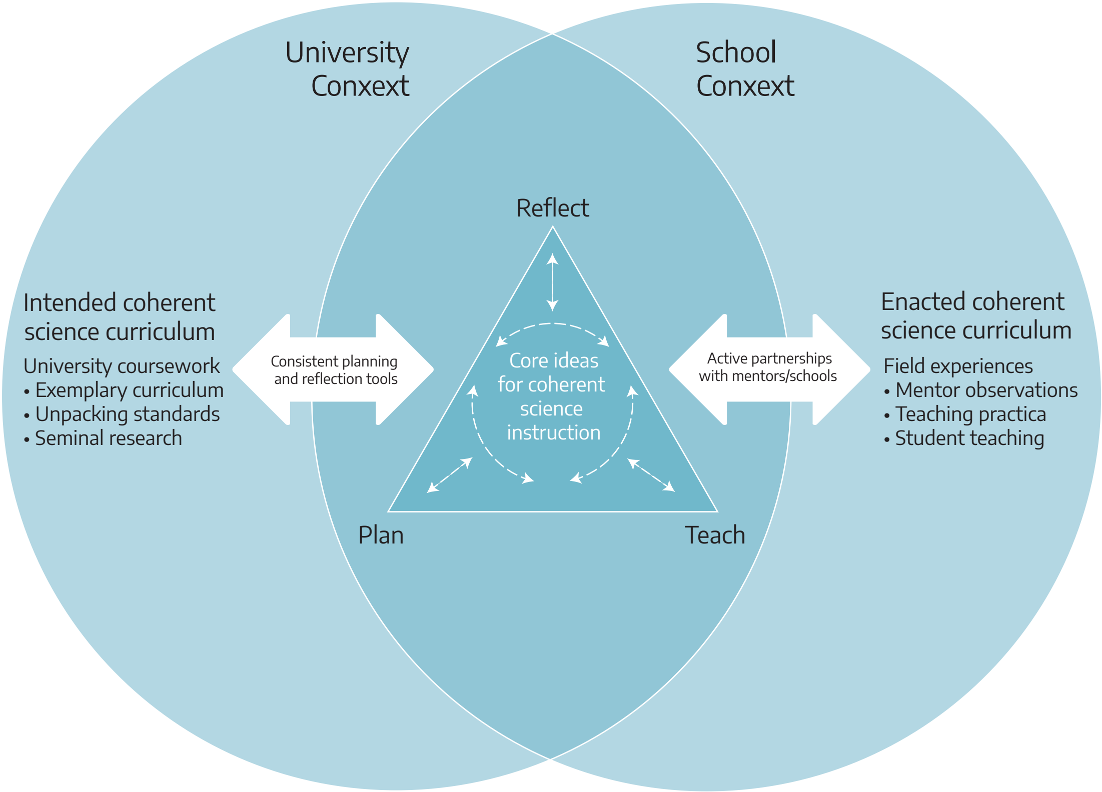

Figure 2.1: Program features and tools for bridging between school and university contexts to support coherent science instruction.

In Chapter 2 of this report, we introduced a theoretical model (Figure 2.1) that was intended to identify key elements of science teacher education programs for promoting the enactment of coherent science instruction and to illustrate relationships between these elements.

Chapters 3-7 in this report illustrated how key elements of the broader theoretical model shown in Figure 2.1 are put into practice in science teacher education programs in PICoSTE partner institutions. In this chapter, we highlight two primary recommendations for science teacher education based upon these strategies and this theoretical model.

Recommendation #1: Identify core ideas for coherent science instruction and focus on them across courses and contexts

The most central recommendation of the PICoSTE project is that science teacher education programs must themselves be coherent if they are to promote the enactment of coherent science instruction in schools. To be coherent, teacher education programs must focus on a small set of core ideas about teaching and learning that preservice teachers see repeated and reinforced across contexts (Hammerness, 2006). Accordingly, core ideas for coherent science instruction are positioned squarely in the center of the PICoSTE theoretical model. Exactly what these core idea are, and how they are manifest in practice, will vary between contexts and depend upon features such as local standards, demographics, school system design, teacher certification requirements, as well as subject-specific ideas. However, we find that these core ideas fall into two categories.

The first category of core ideas for coherent science instruction are core content ideas. To be coherent, science teacher education should focus preservice teachers attention on learning to teach the most central explanatory ideas in each science discipline and considering how they might be developed over long periods of time. These core ideas include, i.e. energy, evolution, plate tectonics, and the nature of matter, and there exists a substantial body of research regarding student thinking about these ideas (e.g., Driver, Squires, Rushworth, & Wood-Robnson, 1994) and theoretical perspectives regarding how core ideas might be mapped into component ideas that build over time (Project 2061, 2001, 2007). More recently, a growing body of literature has been devoted to developing learning progressions (Gotwals & Alonzo, 2012) for core science ideas, which are theoretically and empirically grounded sequences that describe how students develop increasingly sophisticated understandings of core science ideas over time. To date, learning progressions have been outlined for core ideas in various science disciplines like energy (Herrmann-Abell & DeBoer, 2017; Neumann, Viering, Boone, & Fischer, 2013), the nature of matter (Hadenfeldt, Neumann, Bernholt, Liu, & Parchmann, 2016; Stevens, Delgado, & Krajcik, 2009), evolution (Catley, Lehrer, & Reiser, 2005; Wyner & Doherty, 2017), and celestial motion (Plummer, 2014; Plummer & Krajcik, 2010). Science teacher education should leverage existing literature to focus on what is known about the teaching and learning of core ideas in science.

The second category of core ideas for coherent science instruction are core instructional ideas. These core ideas are based on learning theories and research, and they inform how to structure learning activities so that school students are well-supported in developing deep understanding of core ideas over time and using these ideas to make sense of phenomena (Windschitl, Thompson, Braaten, & Stroupe, 2012). Examples of such core instructional ideas are that all new knowledge is built upon existing conceptions, that students should see the same concepts across multiple contexts, and that self-monitoring and metacognition are critical to developing deep and usable knowledge (Bransford, Brown, & Cocking, 2000; National Academies of Sciences, Engineering, and Medicine, 2018). These core ideas may be manifest in the use of global orientations to curriculum design, such as project-based science (Krajcik & Czerniak, 2018), 5E (Bybee et al., 2006), and model-based inquiry (Windschitl, Thompson, & Braaten, 2018), as well as the use of more specific tools and strategies such as Content Representations (CoRes) to unpack science ideas for instruction (Hume & Berry, 2011) and the use of storylines to motivate students' perceived need to know (Nordine, Krajcik, Fortus, & Neumann, 2019).

In the PICoSTE project, we opted not to identify a particular set of core content ideas or core instructional ideas, as these will vary across international and institutional contexts. For example, science standards documents in different countries may differ significantly on the relative emphasis on particular science ideas (Qablan, 2018; Wei & Ou, 2018), and teacher certification systems vary substantially in terms of structure and evaluation criteria (Evagorou, Dillon, Viiri, & Albe, 2015). Thus, it is up to individual science teacher education programs to determine which ideas constitute the core ideas for coherent science instruction and to work to ensure that these ideas are revisited across a range of courses and contexts within the science teacher education programs.

Recommendation #2: Build shared understanding between faculties in university and school contexts

Recommendation #1 emphasizes that science teacher education programs must themselves be coherent in order to promote coherent science instruction, and Recommendation #2 is concerned with making programmatic coherence apparent to learners and extend coherence across contexts. Science teacher education involves the participation of several different faculties, including university science faculty, university teacher education faculty, and school science faculty. While these various faculties are centrally involved in science teacher education, it is often the case that they do not engage in substantive peer-to-peer collaboration on issues relating to science teacher education (Zeichner, 2010). Beyond simply agreeing upon a set of core programmatic ideas, faculty in various courses and contexts must endeavor to make these core ideas explicit through teaching and learning activities in order for programmatic coherence to be apparent to preservice teachers (Canrinus, Bergem, Klette, & Hammerness, 2017).

The PICoSTE model in Figure 2.1 includes bridging components, represented by arrows that span the university and school context, that identify two promising programmatic elements for enhancing collaboration between faculties and making programmatic coherence more apparent to preservice science teachers.

The arrow on the left of Figure 8.1 recognizes the value of a consistent set of planning and reflection tools, used regularly across university coursework and school teaching placements to scaffold planning and reflection around core ideas, in supporting preservice teachers' perceptions of programmatic coherence. For example, the Swedish section of this report describes a planning and reflection tool called the T-CoRe to support teachers in considering how digital technologies can be used to support science learning. By using this tool within university coursework focused on planning instruction and as a means to reflect upon instruction within teaching practica that take place within partner "Practice Schools", preservice teachers can more readily connect their coursework at the university to core ideas about science teaching and use those in their teaching in schools. The arrow on the right of Figure 8.1 recognizes the value of active partnerships with mentors and schools for promoting programmatic coherence. Such partnerships take the complementary role into account that university and school faculty play in science teacher preparation and involve scientists, science teacher educators, and science teachers in regular peer-to-peer collaboration regarding the core aims and activities of a science teacher education program. For example, the Finnish section of this report describes how the science teacher education program at the University of Helsinki is collaboratively developed by representatives from the university faculties of science, bio-science, and educational science along with representatives from university teacher training schools, municipal schools, and the student union. Such collaboration sets the stage for coherence across science teacher education contexts and for mentor relationships in teaching practica that actively complement and reinforce learning at the university.

Implementation

Implementing the recommendations above requires substantial institutional commitments and compromises. To implement Recommendation #1, for example, science teacher education faculty must be willing to surrender some level of autonomy in designing and teaching courses. Faculty at the same institution are likely to disagree on what the content and instructional ideas are that form the core ideas for coherent science instruction; yet, the process of seeking to find some consensus may be valuable on its own, as it may prompt individual faculty to make explicit the core ideas that may have been largely implicit in existing coursework. The core ideas for coherent science instruction represent institutional commitments to the central features of what it means to teach and learn science, so while the process of coming to consensus may be difficult, there is a potentially powerful benefit for preservice teachers to develop commitments to these core ideas. Once faculty members formulate the core ideas for coherent science instructions, it is possible to develop or adapt tools in a way so that it becomes more likely for preservice teachers to carry those ideas forward into their own practice.

Just as the process of defining and making explicit the core ideas for coherent science instruction will carry challenges, so too will initiating and sustaining active partnerships with schools and mentors. In the Finnish model described in this report, collaboration between faculties are supported by institutional structures that often do not exist in other countries, but active exchanges to support high quality mentoring are certainly possible even without such systematically interconnected school and university institutions (e.g., Nordine, Breidenstein, Chapman, & McCool, 2015). No matter the model for active partnerships between school and university faculty, they require nontrivial time commitments for all involved, and these time commitments may not align with broader professional and institutional incentives for school or university faculty.

Science teacher education plays a critical role in promoting the enactment of coherent science instruction that engages learners according to teaching and learning principles that have been well-established in the research and policy literature but that remain stubbornly uncommon in schools. While implementation of the recommendations in this report is far from straightforward, our hope is that they – along with the PICoSTE theoretical model – will provide science teacher education programs with a framework for identifying the most critical focal areas for refining and revising science teacher education programs.

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