Designing and Teaching the Secondary Science Methods Course

An International Perspective

Aaron J. Sickel and
Stephen B. Witzig (Eds.)

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To my wife, Jamison Lorraine, who encouraged and supported me every step of the way. You have been, and will always be the most important person in my life.

– A. J. Sickel

For my wife, Mandy, and our two daughters, Teagan and Annie, whose support and love mean everything to me. This book, and all that I do, is for our family.

– S. B. Witzig

TABLE OF CONTENTS

STEPHEN B. WITZIG AND AARON J. SICKEL

1. SETTING THE LANDSCAPE

Focusing on the Methods Course in Secondary Science Teacher Education

INTRODUCTION

A multitude of countries are interested in improving K-12 science education for the purposes of producing a scientifically literate citizenry and increasing student interest in science-oriented careers. To improve science learning in schools, we must also develop high quality science teacher preparation programs. Although there are numerous outlets for K-12 science teachers to provide insights into their practice (e.g. science education practitioner journals), there are few such outlets for science teacher educators. The purpose of the book is to synthesise detailed descriptions of secondary science methods courses from science teacher educators in different countries across the various continents of the world. We define a 'secondary science methods course' as specific university class designed to prepare pre-service or in-service teachers to teach science in secondary school contexts (ranging between grade 5 and grade 12, depending on the context). The chapters are written by different science teacher educators who teach in a particular country and have purposeful approaches to teaching their course. Individual chapters will describe how the science methods course is situated in the larger teacher preparation program and/or state/national context, followed with details on signature course activities and assessment designs, and how they align with research-supported practices in teacher education. This compilation will provide concrete examples of how science teacher preparation is viewed both similarly and differently across contexts, and allow teacher educators an opportunity to learn from one another about course design. In the final chapter written by the editors, an analysis of the different courses concludes with an articulation of research questions that need to be pursued for improving science teacher preparation from a global perspective.

RATIONALE

In their review of research on science teacher education, Anderson and Mitchener (1994) discussed the three major parts of the 'professional education' component of teacher education programs: educational foundations, methods courses, and field experiences. They discuss how the structure of the 'professional education'

A. J. Sickel & S. B. Witzig (Eds.), Designing and Teaching the Secondary Science Methods Course, 1–8.

component of teacher education had changed very little since before the 1950s. Each of the respective parts has received its share of criticism in the larger teacher education community for issues related to improving coherence, closing the theory/practice gap, and impacting teacher development. However, the potential significance of science methods courses does not go unnoticed, as Anderson and Mitchener state:

> Science methods courses act as the bridge between many areas of the teacher education curriculum, as well as between education and studies in the science departments. Methods courses help prospective teachers integrate knowledge and gain experience in applying this integrated learning in actual school settings with real students or in simulated environments with peers. (p. 17)

We see the science methods course as a pivotal moment in a secondary science teacher's development. It is a place where the pre- or in-service teacher, who to this point has often taken far more science courses when compared to pedagogy, now has the opportunity to think about what it means to move beyond the 'knower' of science to the 'teacher' of science. This can be a powerful experience, as they begin formulating their beliefs, knowledge, and practice for making science understandable, relatable, and engaging for their future students.

While there is a considerable resource bank of K-12 science teaching and learning examples and exemplars to help science teachers improve their practice and learn from others (NSTA Press, 2016), there is not the same wealth of information for science teacher educators to learn from other science teachers' practice. In 2000, Abell introduced us to *Science teacher education: An international perspective*. While this compilation consists of chapters authored by teacher educators from several different countries, the chapters focus on a broad range of issues related to science teacher education (e.g. international partnerships, study abroad programs, and government initiatives regarding pre-service teacher education) and is not specific to the design of secondary science methods courses. This book is also 16 years old and therefore updated information is in critical need. Following up on this resource, Appleton's *Elementary science teacher education: International perspectives on contemporary issues and practice* (2005) consists of a compilation of chapters authored by elementary science teacher educators from several different countries. However, the content of each chapter is not framed by the specific course context. The compilation consists of chapters on a wide range of topics but these are not all specific to course design. More recently, Abell, Appleton and Hanuscin (2010) wrote *Designing the elementary science methods course* to help fill the void in the science teacher educator literature. There are many practical and theoretical insights into designing methods courses, yet the structure of this book also makes it difficult to discern the individual authors' practice in that the entire resource reflects the joint perspective of the three authors. While both Appleton (2005) and Abell et al.'s (2010) focus on elementary science teacher education was a welcome contribution to the field, those science teacher educators that prepare science teachers at the secondary level would have difficulty translating some of the ideas within this book to their course contexts. What is needed is a resource that provides more space and focus on the critical issue of designing and teaching secondary science methods courses.

Currently, there are some resources that secondary science teacher educators can draw form to inform their practice. A new practitioner journal sponsored by the Association of Science Teacher Education in the U.S., *Innovations in Science Teacher Education*, has great potential to begin filling in gaps on teacher education practices associated with science teacher education. Bullock and Russell (2012) provide a compilation of science teacher educators reporting on self-studies of their teacher education practices. The chapters focus on specific research projects embedded in science methods courses, which generated many useful insights. However, in addition to reflecting on a particular component, practice, or strategy for teaching secondary science teachers, fuller descriptions of entire secondary science methods courses are needed, as they lend themselves to reflections on broader curriculum planning in teacher education programs. Whereas individual descriptions of secondary methods courses are occasionally published in peer-reviewed journals (e.g. Vesterinen & Aksela, 2013), a comprehensive secondary science teacher education resource is not available. Compilations such as this book are also needed to provide a variety of perspectives so that readers can compare different ways of approaching the design and teaching of secondary science methods courses.

The approach we took when developing this book with our contributors was to combine the broad-level planning that is employed to design a secondary science methods course with narrow descriptions of signature components embedded throughout – from a holistic institution-wide perspective down to a specific philosophy that undergirds particular lesson and assessment strategies for each course. We would be presumptuous to state that there is one best way to structure a secondary science methods course, and so that was not our intention. We aimed to compile examples from various science teacher educators who are not only innovative in their practice, but are also active researchers of science teacher education and their own practice. We scoured various outlets[1] for the reporting of innovative practices and the design of science method courses and wanted to include authors from each continent of the World[2] in an effort to increase the diversity of the approaches taken. Below we outline the structure of the book, providing a primer for what you should expect as you explore each of the individual chapters in depth. While a chemistry teacher can learn a great deal from focusing on the two chemistry-specific chapters, it is our hope that any secondary science educator will glean insight into the different approaches to design a secondary science methods course from each of the chapters presented.

STUCTURE OF THE BOOK

In the next section of the book, we have organized the chapters around the type of science methods course. In part I, there are four chapters that describe interdisciplinary science methods courses. In part II, there are seven chapters that describe discipline-specific science methods courses – two focused on preparing biology teachers, two focused on preparing chemistry teachers, two focused on preparing physics teachers, and one focused on preparing Earth science teachers (Table 1). Finally, in Part III, we synthesise what we have learned across all eleven course contexts and provide suggestions for research and practice. Below we briefly outline the chapters.

For each context, we asked authors to focus on a science methods course in their teacher preparation program. We wanted them to first situate their science methods course within their program outlining the overall structure of their program and whether there are multiple science methods courses for pre-service teachers. We then asked them to situate their science methods course within their state and national contexts. As they describe the planning that went into their course design, we asked them to discuss the major outcomes and topics for the course, how the

Table 1. Overview of chapter contexts

Discipline	*Authors*	*University*	*Country*	*Continent*
Interdisciplinary	Sickel	Western Sydney University	Australia	Australia
Interdisciplinary	Witzig	University of Massachusetts Dartmouth	United States	North America
Interdisciplinary	Avargil, Spektor-Levy, & Zion	Bar-Ilan University	Israel	Asia
Interdisciplinary	El-Deghaidy	American University in Cairo	Egypt	Africa
Biology	Janssen & van Driel	Leiden University	Netherlands	Europe
Biology	Munford, Tavares, Coutinho, & Neves	Universidade Federal de Minas Gerais	Brazil	South America
Chemistry	Aydın-Günbatar & Demirdöğen	Yuzuncu Yil University	Turkey	Asia/Europe
Chemistry	Mavhunga & Rollnick	University of Witwatersrand	South Africa	Africa
Physics	Postlethwaite & Skinner	University of Exeter	United Kingdom	Europe
Physics	Kang	Korea National University of Education	South Korea	Asia
Earth Science	Rivet	Columbia University	United States	North America

topics are sequenced, what are their major assessments, as well as explicitly stating their reasoning behind each of these instructional decisions. After this overview, we wanted each author to drill down into the specifics of their course and walk us through a specific lesson or two and explain how and why they structured the lesson in that particular way. We wanted this topic to be one that they believed was signature to their course with the idea that this would provide insight into the priorities that are placed in each of the course contexts. In this vein, each author then described the design of one or two signature assessments in their methods course and what they have learned from per-service teachers' work on those assessments. Finally, each author concluded their chapter by describing what works well in their course and discussing areas they are currently trying to improve in future offerings.

Part I: Interdisciplinary Science Methods Courses

In this section we have organized four chapters that are not specific for any one discipline of science – they are designed to prepare all pre-service science teachers in their program. First, Sickel describes preparing grade 7–10 science teachers at Western Sydney University in Australia using an approach based on the 5E learning cycle (Bybee et al., 2006). He focuses on teacher discourse practices as his signature lesson, and has students develop their own 5E lesson plan as a summative assessment in the course. Witzig, at the University of Massachusetts Dartmouth in the U.S., describes preparing grade 5–12 science teachers through a cycle of engage, investigate, and constructing explanations (Witzig & Campbell, 2015). He describes how he models a conversation in the classroom around a photosynthesis simulation laboratory. The course design scaffolds learning experiences for pre-service science teachers and culminates with them developing a unit plan as the summative assessment. Avargil and colleagues, at Bar-Ilan University in Israel, prepare middle and high school pre-service science teachers to become scientifically literate through research. Their signature lesson is focused on modelling in science (Clement & Rea-Ramirez, 2008), and they describe an online discussion forum with reflective question prompts as an assessment strategy in their course. In the final interdisciplinary methods course, El-Deghaidy from the American University of Cairo in Egypt describes a science, technology, engineering, arts and mathematics (STEAM) focused pedagogy course for grade 10–12 pre-service teachers. In addition to having future teachers make sense of STEAM education, she describes how they use unit and lesson plans to help integrate the different disciplines together through inquiry-based learning. For assessment, she describes an integrated STEAM unit that teachers design.

Part II: Discipline-Specific Science Methods Courses

As seen in Table 1, this book contains seven chapters that focus on a discipline specific science methods course. In biology, Janssen and van Driel from Leiden

University in the Netherlands describe how they organize their course to prepare secondary teachers through a learning progression that develops a biology teaching repertoire specific for each pre-service teacher. For assessment, they ask their pre-service teachers to document their intentions and teaching experiments as they develop their individual teaching repertoire. Also focused on preparing biology teachers, Munford and colleagues at the Universidade Federal de Minas Gerais in Brazil, prepare teachers to teach high school biology as well as general science from fifth-ninth grade. They promote biology teaching and learning through an argumentation approach (Andriessen, 2007; Zohar, 2007) as well as through discursive practices (Mortimer & Scott, 2003). For assessment, they describe a biology teaching portfolio that each pre-service biology teacher creates, which includes reflections and artifacts generated across courses and their teaching practicum experiences.

Chemistry teacher preparation is the focus of two chapters. First, Aydın-Günbatar and Demirdöğen at Yuzuncu Yil University in Turkey, describe how their methods course prepares pre-service teachers to teach chemistry in grades 9–12 focusing on developing their pedagogical content knowledge (PCK) (Abell, 2007) for specific chemistry topics. For assessment, they use a revised content representation (CoRe) tool (Aydin et al., 2013) to assess the pre-service chemistry teachers' lesson plans. Also in chemistry, Mavhunga and Rollnick from the University of Witwatersrand in South Africa prepare grade 10–12 teachers also using PCK (Shulman, 1986) as an organizer. They focus on topic-specific PCK development in chemistry and also assess pre-service teachers using the CoRe (Loughran, Berry, & Mulhall, 2004).

The preparation of physics teachers is described in two chapters. Postlethwaite and Skinner from the University of Exeter in the U.K. prepare pre-service teachers to teach physics to secondary students (age range 11–18). They use a socio-cultural perspective that has pre-service teachers reflect on what they observe as well as their own practice, as demonstrated through an electricity workshop embedded in the methods course. For assessment, they describe how they engage the pre-service teachers in developing and reporting on an action research project conducted during their field placement. Kang, at the Korea National University of Education in South Korea, also prepares secondary pre-service physics teachers. The signature lesson described is focused on learning theories and introducing pre-service physics teachers to concepts on how students think and how their learning can be advanced through discussion with a more knowledgeable other. For assessment, Kang describes using formative assessments (including class discussions) for 70% of the course grade and a summative essay test based on course activities for the remaining 30%.

Our final discipline-specific book chapter describes preparing pre-service teachers to teach grades 7–12 Earth science. Rivet, at Teachers College at Columbia University in the U.S., utilises a PCK approach (Gess-Newsome & Lederman, 2001; Magnusson, Krajick, & Borko, 1999) to help pre-service teachers develop their own PCK for Earth science teaching. PCK development is modelled through her lesson on Earth system structure and processes and assessed through a summative PCK project where pre-service teachers develop a resource guide to teach a specific topic in Earth science.

Part III: Synthesis across Contexts

In this closing chapter, we, as co-editors of the book, have synthesised what we have learned across each of the individual methods courses. We discuss the themes that cut across each of the three major sections of the chapters (planning, classroom practice, assessment), discuss the role of context in shaping course designs, and conclude by discussing potential trajectories of future scholarship related to secondary science methods courses, as well as what readers can gain from this international compendium.

What we hope that this book accomplishes is to start a conversation related to insights from the design of existing science methods courses as well as innovative ways of preparing secondary teachers of science.

NOTES

1 Our search included the major science education journals as well as abstracts from science educations conferences such as the NARST (https://www.narst.org/) and ASTE (http://theaste.org/).

2 Each continent is represented except for Antarctica.

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PART I

INTERDISCIPLINARY SCIENCE METHODS COURSES

AARON J. SICKEL

2. THE 5E MODEL AS A FRAMEWORK FOR FACILITATING MULTIPLE TEACHER EDUCATION OUTCOMES

A Secondary Science Methods Course in Australia

INTRODUCTION

Australia is a large country geographically with a relatively small population of approximately twenty four million people. Like many countries, the health of the economy fluctuates over time, but Australia has enjoyed a mostly healthy and stable trajectory of economic output over the last forty years. There is now a strong push to develop STEM education throughout the country, not only due to the need for more students to enter into STEM professions, but also due to concerns about science and mathematics literacy (Australian Council of Learned Academies, 2013). While Australia students have ranked modestly well on international tests, including the Programme for International Student Assessment (PISA) and the Trends in International Mathematics and Science Study (TIMSS), a longitudinal analysis reveals that Australia's science scores are mostly stagnant or decreasing, while other countries are showing improvement (Thompson, Bortoli, & Buckley, 2013). Thus, there is increased pressure on initial science teacher education programmes to develop effective science teachers who possess the knowledge and skills to improve K-12 students' achievement and interest in science.

Secondary Science Education in Australia

Secondary education in Australia consists of grades 7–12. There is a national curriculum developed by the Australian Curriculum, Assessment, and Reporting Authority (ACARA). This curriculum broadly defines content descriptors in each subject area. In science, the descriptors are divided among three categories: Science Understanding, Science as a Human Endeavour, and Science Inquiry Skills. The curriculum represents the most fundamental understandings and skills that all Australian students are to develop. The curriculum also presents cross-curriculum priorities (e.g. understanding Aboriginal and Torres Strait Islander histories and cultures) and general capabilities (developing skills in literacy and numeracy) that span all subjects (ACARA, 2013).

A. J. Sickel & S. B. Witzig (Eds.), Designing and Teaching the Secondary Science Methods Course, 11–31.

Each state within Australia has developed its own science curriculum that incorporates, yet exceeds, the national curriculum in scope and specificity. For example, whereas the national curriculum designates that year 9 students should understand that "values and needs of contemporary society can influence the focus of scientific research," (ACARA, 2013) an outcome in the New South Wales (NSW) science syllabus is more specific with its requirement that a student "discusses the importance of chemical reactions in the production of a range of substances, and the influence of society on the development of new materials" (Board of Studies, 2012).

Students in grades 7–10 experience a curriculum that moves back and forth among the science disciplines of physics, chemistry, biology and Earth science (and for some schools, the curriculum is integrated across the disciplines). After grade 10, students then enrol in selected subjects for the Higher School Certificate (HSC) in grades 11 and 12. This could include a specific class in biology, chemistry, physics, Earth and Environmental Science, or Senior Science (curriculum cutting across all science disciplines). Every HSC class concludes with a formal exam developed by the NSW Department of Education. Students' exam scores across all of their selected subjects contribute to one over-arching score, which is then used as one criterion for entry into university. The curriculum for each science subject in grades 11–12 has a similar structure to grades 7–10 with its focus on science understanding, science as a human endeavour, and science inquiry skills, though they contain a significant amount of advanced content in the category of science understanding.

Teacher Education Program at Western Sydney University

Secondary teacher education programs in Australia vary in structure and length (for more information, see Mayer, Pecheone, & Merino, 2012). For example, there are undergraduate programs that integrate education and content coursework, lasting four or five years. Another popular model is for students to obtain a three-year undergraduate degree in a particular content area (e.g. biology) and then enrol in a two-year masters-level graduate program in education as they work toward initial certification. The latter model exists at Western Sydney University.

I teach in a master's graduate program focused on initial certification for secondary teaching. The program consists of sixteen courses taken over two full years, with four courses taken per semester (each semester is 15 weeks). For both the second and third semesters of the program, pre-service teachers take three courses for the first 9 weeks (two of which are subject-specific methods courses), and then the fourth course is spent in the remaining 6 weeks out in a school as a professional experience placement. The methods courses meet for three hours each week across the first 9 weeks of the semester. In addition to the two courses focused on professional placements in schools and four subject-specific methods courses, pre-service teachers complete a wide range of other courses, which focus on positive learning environments, adolescent development, diversity, research in education, and special education.

As the secondary science teacher educator in the School of Education at Western Sydney University, it is my role to design, coordinate, and staff the teaching of all secondary science methods courses in the secondary masters program. Western Sydney University offers five different science methods courses. Two of the courses are titled 'Science Curriculum 1A' and 'Science Curriculum 1B,' both of which address the teaching of science in grades 7–10 and are offered in the second semester. These courses integrate the teaching of all science disciplines to reflect the grades 7–10 curriculum. There are three different courses labelled as 'Science Curriculum 2 (SC2)' including SC2-Biology, SC2-Chemistry, and SC2-Physics. Each of these courses focuses on teaching the HSC curriculum in grades 11–12 for a particular science subject, and are offered in the third semester.

Science Curriculum 1A focuses on an introduction to science teaching in grades 7–10, and is the course I discuss in more detail below. Science Curriculum 1B focuses more heavily on curriculum mapping and teaching skill development (e.g. developing their skills with questioning during micro-teaching exercises). As the SC2 courses each address specific science subjects, they focus more on the applications of discipline-specific pedagogies. For example, pre-service teachers learn about modelling the cell cycle in biology education, levels of representation to understand kinetic-molecular theory in chemistry education, and the role of experiments to understand electricity in physics education. In these courses, pre-service teachers work on explicitly developing pedagogical content knowledge, or PCK (Magnusson, Krajcik, & Borko, 1999), for selected topics in the HSC curriculum. These units also focus heavily on teaching each discipline to learners of diverse backgrounds, including (but not limited to) economic, cultural, ethnic, and/or linguistic backgrounds.

In NSW, pre-service teachers can become certified to teach one or two disciplines at the secondary level. Those pre-service teachers who only study science education will take Science Curriculum 1A and 1B, as well as two of the three SC2 subjects (e.g. biology and chemistry). For pre-service teachers who study two disciplines (e.g. science and math), they too will complete two of three SC2 courses, but only Science Curriculum 1A and then the 1B curriculum course in their other subject (and thus will learn about similar issues of pedagogy in the 1B course of the other subject).

PLANNING

Factors Informing Course Design

It has long been established that pre-service teachers enter into their programs with existing beliefs and perspectives about teaching and learning, and often these beliefs are informed by years of observing their previous teachers in K-12 settings (Jones & Leagon, 2014). While one can certainly learn valuable information from such observations, as teacher educators we are often charged with the responsibility to help pre-service teachers consider different approaches to teaching than what they may have experienced as learners – in particular, shifting from transmission models of learning to more constructivist models. Thus, I feel compelled to not only introduce constructivist approaches, but also use these pedagogies in the design of my methods courses.

In the design of any methods class, I feel the need to balance what is required by local education authorities and what I believe is necessary to consider when planning science instruction based upon educational research. Regarding the former responsibility, the Australian Institute for Teaching and School Leadership (2014), has established graduate standards for teacher preparation. There are seven such standards, which focus on the following domains of professional knowledge, practice, and engagement:

- Know students and how they learn
- Know the content and how to teach it
- Plan for and implement effective teaching and learning
- Create and maintain supportive and safe learning environments
- Assess, provide feedback, and report on student learning
- Engage in professional learning
- Engage professionally with colleagues, parents/carers and the community

All science methods courses map to these standards, though some courses address more standards than others. Regarding educational research, one exercise I completed in my early days of developing as a teacher educator was to write out what I considered to be critical components of meaningful learning. My reading of the book, *How people learn: Brain, mind, experience, and school* (Bransford, Brown, & Cocking, 1999), and subsequent readings about research in the learning sciences (e.g. Sawyer, 2014) have led me to identify four core, research-supported principles, as identified in turn. Meaningful learning can take place when there is consideration of:

- learners' prior knowledge – learners are able to assimilate new information when they can connect it to existing knowledge structures
- collaborative, rich experiences – in addition to interacting with the world around them, learners typically benefit from the opportunity to engage in a shared experience with others, so that new ideas can be wrestled with, challenged, and ultimately internalized
- big ideas – learners are better able to assimilate, retrieve, and transfer new information when it is chunked together as an interconnected network of big ideas rather than a list of discrete facts
- formative assessment and reflection – learners are better able to assimilate, retrieve, and transfer new information when they have ongoing opportunities to receive feedback and reflect on their learning process

These four principles are essential to all learning experiences, and therefore I believe it is my role to not only to help my pre-service teachers draw upon these principles as they plan secondary science instruction, but also to incorporate them in the design of my science methods course.

In the design of Science Curriculum 1A, after establishing the fundamental aspects of teacher education and general learning principles (neither of which are specific to teaching science), I then considered how I could help pre-service teachers think about planning science instruction. I became introduced to the 5E instructional model (5E model) as an undergraduate pre-service science teacher in the United States. I was intrigued by this model when I first learned about it, primarily because it represented a sequence of instruction that seemed more engaging for the learner, better reflective of the nature of scientific work, and was different from the typical science instruction I experienced in K-12. I have since engaged in research investigating the affordances of using the 5E model in various contexts (e.g. Sickel & Friedrichsen, 2015; Sickel, Witzig, Vanmali, & Abell, 2013). The 5E model was developed by Rodger Bybee and the Biological Science Curriculum Study in the 1980s (for a comprehensive review and description of the 5E model, see Bybee et al., 2006). It utilises a constructivist sequence of instruction, with the following five phases:

- Engage – students consider a new concept through a motivating and intriguing activity, which allows the teacher to learn about students' prior knowledge
- Explore – students participate in shared experience, which allows them to initially construct ideas about a concept
- Explain – students develop scientific claims to explain what was learned in the Explore phase activity, while the teacher often guides the sense making process
- Elaborate – students apply concepts to new situations and contexts
- Evaluate – students have an opportunity to demonstrate their summative understandings of the concept

Studies comparing this constructivist sequence of instruction to traditional modes of science instruction have shown positive science learning results for the 5E model (Bybee et al., 2006; Wilson, Taylor, Kowalski, & Carlson, 2010). In addition to its use for teaching K-12 science, Hanuscin and Lee (2008) discussed how teacher educators can develop their own 5E unit for introducing the 5E model to pre-service teachers. This type of instruction has much appeal to me, as I have found that pre-service teachers engage more positively with my instruction when they see that I am 'practicing what I am preaching.' In addition to this, I was able to see clear connections among the Australian teacher education standards, four principles of learning mentioned above, and the inherent design of the 5E model. I therefore decided to design my nine-week Science Curriculum 1A course as one expansive 5E unit about learning to teach science. This extends Hanuscin and Lee's (2008) thinking from one instructional unit to the design of an entire course.

In the sections below, I describe how the 5E model has informed the design of Science Curriculum 1A. While pre-service teachers work through each phase as learners of science teaching, I have found opportune moments to introduce the four principles of learning, specific science education topics (e.g. working scientifically, discourse practices in science teaching, PCK), and the 5E model itself. A summary of these connections can be found in Table 1. In the following section, I will discuss the design of the Science Curriculum 1A course at Western Sydney University, using the 5E model as a conceptual organizer for the entire course.

5E Unit for Entire Science Methods Course

Engage. In week 1, the purpose of my instruction is to facilitate an opportunity for pre-service teachers to make explicit their current ideas about teaching science. I accomplish this with two major activities. First, I ask them to complete a lesson planning task. Drawing on their current knowledge, they write out plans for two consecutive lessons for a selected content outcome in the grades 7–10 science curriculum. An example outcome includes, "explain that predictable phenomena on the Earth, including day and night, seasons and eclipses are caused by the relative positions of the Sun, the Earth and the moon (Earth Science, grades 7–8) (Board of Studies NSW, 2012). After completing the task, pre-service teachers group together by topic outcome and share their ideas with each other, and then with the whole class. We discuss some of the basic features of their lesson designs. Typically, I have found that pre-service teachers are apt to begin their lesson with direct instruction about the central science concept, and then have students engage in an activity related to the topic.

During our class discussion, I record ideas about central features of pre-service teachers' lesson designs. The following examples represent typical features: (1) the introduction of science terminology to 'break it down' upfront, (2) allowing students to participate in activities to 'reinforce' the concept, and (3) the importance of making science learning 'fun.' Beyond these features, often there are also disagreements. Some pre-service teachers advocate for more activity-based learning than others. Some believe students should work in groups, while others believe it should be individually-based. The purpose of this class discussion is to record our ideas about teaching so that we can revisit them throughout the course. At this point, I do not interject my ideas about teaching science.

The second part of the Engage phase is to elicit pre-service teachers' ideas about the nature of science and scientific work. Pre-service teachers are asked to read selected first-hand accounts of scientific work (e.g. investigations into the impact that led to the Cretaceous-Paleogene extinction event, or the work that led to discovering the Higgs-boson particle). Along with this, they reflect on how they designed their lesson task to allow students to participate in scientific work. Again, we record ideas as a class. Generally, pre-service teachers focus their ideas on the use of repeatable experiments, drawing on large amounts of evidence to 'prove' or 'disprove' a hypothesis, and the removal of bias in scientific analysis.

Table 1. Outline of science curriculum 1A course

Week	*5E Unit as course organizer*	*Content: Science education topics*	*Content: Core Learning Principles – Prior knowledge (PK), Big ideas (BI), Collaboration (C), Formative assessment (FA)*	*Australian teacher education standards*	*Assessment*
1	*Engage* Lesson planning task – how do you design science instruction?	*Nature of Science* What is science to you? *Students' Prior Knowledge* How can you diagnose prior knowledge?		#1: Know students and how they learn	Begin developing interview protocol; distinguish between phenomenon and concept
2	*Explore and Explain* Participate in Engage, Explore, and Explain phase of 5E unit on natural selection; Identify key actions/roles	*Preconceptions* Explore commonly held alternative conceptions *Formative Assessment* Review types of formative assessment	*Learners' Perspective…* PK: Pre-service teachers have different ideas about natural selection C: Pre-service teachers complete activity together	#1: Know students and how they learn	Peer-review of interview questions
3	*Explore and Explain* Participate in Elaborate and Evaluate phase of 5E unit; Identify key actions/roles	*Lesson Planning:* Reflect on natural selection lesson plan; Discuss 'connecting prior knowledge to new experiences'	C: Pre-service teachers complete the elaborate activity together BI: Pre-service teachers construct components of natural selection	#2: Know the content and how to teach it	Peer-review of diagnostic assessment

(*Continued*)

Table 1. (Continued)

Week	*5E Unit as course organizer*	*Content: Science education topics*	*Content: Core Learning Principles – Prior knowledge (PK), Big ideas (BI), Collaboration (C), Formative assessment (FA)*	*Australian teacher education standards*	*Assessment*
4	*Explore and Explain* Participate in abbreviated 5E unit on heat/temp – discuss safety with science experiments	*Sequencing Science Instruction* Reflect on 5E model *Working Scientifically* Connect activities to features of inquiry	FA: Pre-service teachers learn that they were being assessed throughout the 5E model	#2: Know the content and how to teach it #4: Create and maintain supportive and safe learning environments	Peer review of exploratory activity
5	*Explain* Reflect on 5E units and formalize definition of 5E model Revisit Key Learning Principles and their connection to 5E model	*Teacher/Student Discourse During Lessons* Explore questioning and feedback during lessons *Nature of Science* Revisit pre-service teachers' ideas about scientific work	*Teachers' Perspective…* PK: Examine how teacher elicits what students already know BI: Examine how to scaffold core ideas C: Examine strategies for collaborative discourse	#3: Plan for and implement effective teaching and learning #4: Create and maintain supportive and safe learning environments	*Assignment 1 Due* • Interview • Synthesis of preconceptions • Diagnostic assessment and exploratory activity
6	*Elaborate* Apply understandings of each 5E lesson phase to different teaching strategies; Discuss how socio-scientific issues can be taught through the 5E model	*Science Teaching Strategies* Explore different teaching and assessment strategies *Socio-Scientific Issues* Introduce SSI; Examine connections between SSI and secondary curriculum	BI: Examine how different 5E units focus on core ideas C: Examine strategies for collaborative student work during 5E activities FA: Examine opportunities to assess understanding throughout 5E units	#2: Know the content and how to teach it #3: Plan for and implement effective teaching and learning	Map out big ideas for developing your own 5E unit

7	*Elaborate* Present examples of SSI and how to incorporate them into a 5E unit	*Socio-Scientific Issues* Explore pedagogical perspectives of teaching SSI	Continue discussion of core learning principles from weeks 5 & 6	#3: Plan for and implement effective teaching and learning	Peer feedback on lesson plans for 5E unit
8	*Elaborate* Work on developing your own 5E unit	*Designing Science Teaching Materials* Design materials and tasks according to objectives, diversity, and differentiation		#3: Plan for and implement effective teaching and learning #5: Assess, provide feedback, and report on student learning	Peer feedback on teaching materials and summative assessment for 5E unit
9	*Evaluate* Revisit lesson planning task from week 1; Reflect on course design as one 5E unit	*PCK in Science Education* Link developed knowledge to PCK	*Teacher Educator's Perspective…* Reflect on all learning principles in the design of the course	#6: Engage in professional learning	*Assignment 2 Due* • 5E lesson plans • Teaching materials • Justification essay

Explore. After eliciting pre-service teachers' ideas about designing science lessons and how science works, I then ask them to participate in a series of activities that represent the Explore phase of my 5E unit. In weeks 2 and 3, pre-service teachers participate in a sequence of high school science lessons as learners. I teach a 5E unit that introduces the concept of natural selection and teach it in the same way as I would to grade 10 students. The purpose of this experience is for pre-service teachers to explore an alternative sequence of instruction when compared to their lesson planning task. Thus, participating in the 5E unit represents the Explore phase of my over-arching 5E unit about teaching science.

For the Engage phase of the natural selection 5E unit, I introduce formative assessment probes similar in style to those developed by Page Keeley and colleagues (Keeley, Eberle, & Tugel, 2007). Designed by Dianne Anderson and Kathleen Fisher (for examples, see Anderson, 2012), one probe asks students which guppy out of four is the 'most fit,' confronting misconceptions relating to the notion of 'big and strong' and testing students' understanding of fitness as relating to generating offspring. The second probe asks students to explain what happened to a population of moths during the industrial revolution and tests their ideas about how a population's trait could change in frequency over time. Pre-service teachers record their ideas in journal, and then we discuss them as a class.

For the Explore phase, pre-service teachers work in pairs to examine data collected by Peter and Rosemary Grant (Weiner, 1994), who analysed changes to traits in finch populations during the 1970s at the Galapagos Islands. The website (http://www.bguile.northwestern.edu) with this data was created by Reiser and colleagues, and provides a large range of quantitative data (measurements of finches' wing length, leg length, beak length, and weight) and qualitative data (field notes describing finch behaviour relating to foraging) (Reiser, Tabak, Sandoval, Smith, Steinmuller, & Leone, 2001). The purpose of this task is for pre-service teachers to explain why so many finches died during the 1970s, and why some survived. Through a series of lessons in which pre-service teachers analyse data, and continuously make and revise claims, most will eventually come to the conclusion that a drought led to a significant decrease in plant life on a particular island. Plants that produced hard seeds survived at a much higher rate when compared to soft seeds. Therefore, only finches with longer beaks were able to crack the hard seeds and survive to reproductive maturity. Thus, finches that survived had larger beaks and were the only ones reproducing, leading to an average increase in beak length over time.

After pre-service teachers write out their explanations and present them to the class, we then enter into the Explain phase of the exemplar natural selection 5E unit. I model a whole-class discussion that could unfold in a grade 10 classroom. I ask the pre-service teachers to report their claims and supporting evidence on large pieces of paper and present them to the class. We then start synthesizing the major ideas. Over time, I try to scaffold their discussion toward the major components that led to the changes in the population. Specifically, we link what happened to the finches to four 'big ideas' – genetic variation, environmental constraints, differential reproduction, and heredity of traits. We then identify these ideas as the major components of natural selection.

After arriving at a consensus understanding about natural selection, I present a scenario for pre-service teachers to consider in small groups. They examine the bone structure of a modern cheetah and compare it to a common ancestor, *Pseudaelurus* (*Pseudaelurus* had forelimbs that are shorter and thicker than the modern cheetah). Next, they are asked to develop a story that explains how and why the bone structure changed over time while using the four components of natural selection learned from the Explain phase. In this activity, the purpose is for students to apply the components of natural selection to another situation to explain a real-world phenomenon and represents the elaborate phase of natural selection 5E unit.

For the evaluate phase, the pre-service teachers revisit the answers to the formative assessment probes in the Engage phase, and are asked to consider whether they want to change them or add explanatory information.

After participating in the natural selection 5E unit, I walk them through another 5E unit on heat and temperature in week 5. They do not actively participate in every lesson phase, but are provided another opportunity to see this type of instruction used for a different science topic.

Explain. In accordance with the 5E model, there is often a back and forth between the Explore and Explain phases with unit design. Throughout weeks 2–4, as pre-service teachers are participating in secondary-level 5E units as learners, we are continuously taking a 'step back' from the exemplar unit and reflecting on what is happening. Pre-service teachers are asked to record what I am doing as the secondary science teacher and what they are doing as high school students during each lesson phase. We then discuss the purpose of each phase. During the Engage phase of the natural selection unit, pre-service teachers learn that they do not all share the same ideas about how populations change over time. They also learn that a teacher can elicit students' ideas about a real-world phenomenon without immediately telling students the scientifically accurate idea. During the Explore and Explain phases, they learn that the typical sequence of instruction can be flipped. They see that there is more motivation to develop a scientific explanation when a real-world phenomenon serves as an anchoring experience. During the Elaborate and Evaluate phases, pre-service teachers see the importance of asking students to take their conceptual ideas and test them out in new situations to see if they are useful in explaining other phenomena.

After reflecting on their own experience with the natural selection 5E unit, I then explain that I have taught this specific unit to grade 10 students and collected data. I talk them through examples of grade 10 student work from each lesson phase, and we compare that work to the pre-service teachers' experiences as learners. I have found this to be a powerful experience for pre-service teachers, as it allows them to see an authentic example of a 5E unit put into practice. I also discuss changes I made to my instruction as I learned about students' ideas. In the first iteration of my teaching grade 10 students, they did not show much improvement in their understanding of biological fitness. I ask the pre-service teachers to consider why this might have happened. Many of them will propose that the Explore phase finch activity could actually reinforce the misconception that being fit means 'big and strong,' as it was only the finches with longer beaks that could crack open the hard seeds and survive in the arid environment. I found this to be a problem with my initial instruction, and therefore expanded upon my Elaborate phase activities to include more examples of natural selection which did not fit the 'big and strong' conception of fitness.

During the Explain phase discussions, we discuss big ideas in science teaching, including the details of articulating clear learning objectives and planning a particular lesson, and sequencing science instruction. We also continuously revisit the following question: "What are the key components of learning throughout the 5E model?" We talk about ideas associated with finding out what students thinking prior to explicit instruction (Engage), the role of facilitating collaborative, shared experiences (Explore), the focus on the essential components of natural selection as a 'big idea' or conceptual framework as opposed to discrete facts (Explain and Elaborate), and the role of ongoing assessment and reflection (Engage through Evaluate). Once these ideas become explicit, I have pre-service teachers examine excerpts of readings on the learning sciences (e.g. Sawyer, 2014) to help them understand that these ideas are research-supported and reflect our current knowledge about how to facilitate meaningful learning.

Another pivotal point of discussion is to discuss how pre-service teachers were engaged in authentic scientific work throughout the 5E unit. The science curriculum in NSW specifically requires students to 'work scientifically.' Pre-service teachers identify how they were engaged in answering scientific questions (related to why certain finches survived), analysing data (by using real-world data from Peter and Rosemary Grant to develop an explanation), and communicating scientifically (reporting their claims and evidence). We make similar connections to the heat/temperature 5E unit as well.

The last part of the Explain phase in the class takes place during week 5. Here, we focus our attention on the discourse practices that were present throughout the natural selection unit. Orchestrating discourse and working with students' ideas to develop a scientific story is an essential part of science instruction (Mortimer & Scott, 2003). After reflecting on how I led discussions, pre-service teachers watch other video cases of science instruction to help them identify essential practices. This lesson is further explained in the 'classroom practice' section below.

Elaborate. The purpose of the Elaborate phase is to take a conceptual idea and apply it to a new context or situation. By the mid-point of the semester, pre-service teachers have been constructing their understandings of the 5E instructional model as an approach to science instruction, with articulations of practice for each lesson phase. The primary way in which pre-service teachers are asked to apply their knowledge is that they must design their own 5E unit for a topic in the secondary curriculum that is different from the topics I taught (natural selection and heat/temperature). While they begin to plan their units, they must consider many different examples of application.

First, pre-service teachers are asked to explore alternative strategies that could be utilized for each 5E lesson phase. For example, teachers could use a demonstration or brainstorming session for the Engage phase as opposed to the formative assessment scenario I used. The Explore phase could incorporate a first-hand investigation rather than an analysis of existing data. The Explain phase could draw upon model building exercises, the Elaborate phase could include a design experiment, and the Evaluate phase could incorporate a concept map. Pre-service teachers begin to see a host of possibilities, and we discuss the notion that the selection of activity should be based on their curricular objectives and how they can best support students in achieving them.

Second, in weeks 7 and 8, I introduce the concept of socio-scientific issues in science education (Presley et al., 2013). I have chosen to spend more time on this topic due to the Australian and NSW science curriculum. There are many examples of content statements in the curriculum that lend themselves to socio-scientific issues as contexts for learning. For example, a biology topic in grades 7–8 includes, "give examples to show that groups of people in society may use or weight criteria differently in making decisions about the application of a solution to a contemporary issue, e.g. organ transplantation, control and prevention of diseases and dietary deficiencies" (Board of Studies, 2012). Moreover, sustainability is mentioned as a cross-curriculum priority, and is an important component of the Australian curriculum (ACARA, 2013). Thus, we explore these types of topics and discuss how a 5E unit might look different when framed around a socio-scientific issue. At the core of these discussions, it is important to note that there must be explicit designs for students to discuss the social, economic, and/or political considerations of socio-scientific issues along with scientific aspects, in addition to acknowledging that solutions or answers cannot easily be defined as completely 'correct' or 'incorrect' (Presley et al., 2013). For example, if pre-service teachers were to design a 5E unit for a topic associated with renewable energies, students might explore a specific product with library research, and then ultimately be divided on supporting a specific renewable energy (solar, wind, hydroelectric) based on social and economic factors. These topics are messy and complex in the real world, and that complexity should be embraced in the classroom as well.

Evaluate. Evaluating student learning should take place throughout all instruction. However, I still find it useful to have dedicated time set aside for a more formal and summative evaluation of student learning. For my class, the purpose of the Evaluate phase, which takes place in week 9, is to reflect on what was learned throughout the activities. Pre-service teachers are asked to look back at their original lessons they designed during week 1, and write out how they could improve it based on what was learned in the class. Pre-service teachers are often astonished at how many ideas they now have to improve their lessons. One of the most common issues we discuss is the change that takes place whereby pre-service teachers realise that students can engage in collaborative, engaging activities and that they must help support conceptual understanding or skill development (as opposed to just doing it for 'fun.')

Next, I ask the pre-service teachers to consider the components or principles of teaching science that they feel they developed. We are eventually able to map their ideas to four knowledge bases discussed by Magnusson et al. (1999); knowledge of curriculum, knowledge of learners, knowledge of instructional strategies, and knowledge of assessment. As I introduce the construct of PCK, we discuss the notion that science teachers develop knowledge in the aforementioned areas and integrate it to teach specific topics. This type of specialised knowledge develops throughout teachers' careers, and has been shown to correlate to improved student understanding (e.g. Kanter & Konstantopoulos, 2010). Pre-service teachers then reflect on how they developed PCK during their work on both assessments, when they designed instruction for a specific topic by considering each of the four knowledge bases.

Following a discussion around PCK, we then discuss the science methods course. I ask them to consider how the 5E model relates to my overall design of the course. We then work together to map out the 5E unit for teaching about science teaching described in the planning section of this chapter. I ask them to consider the four learning principles we addressed when learning about the 5E model. They identify places in the course where each was present in my planning and teaching. Regarding 'prior knowledge,' they look back at the lesson planning task as evidence that I wanted to gauge their prior ideas about teaching science. For the concept of 'big ideas,' pre-service teachers can identify many of the over-arching frameworks that were continuously revisited throughout the course, including the 5E model, working scientifically, and the four learning principles. Regarding 'collaboration,' pre-service teachers note the fact that the 5E model was experienced and explained together as a class, and that a community approach to understanding was utilised for all learning outcomes. Last, regarding 'formative assessment,' pre-service teachers quickly point to the notion that they were repeatedly asked to revisit their thinking about the nature of science, sequencing science lessons, and lesson planning.

CLASSROOM PRACTICE

A signature lesson in Science Curriculum 1A focuses on teacher discourse practices. This lesson occurs during week 5 during the 'Explain' phase of the course-level 5E unit, after pre-service teachers have experienced two exemplar 5E units as learners. One of the most difficult tasks for a teacher when facilitating a 5E unit is to guide the development of the scientific story as students transition from the Explore phase to the Explain phase. While it is the goal for students to have an active role in developing explanations, it is often the teacher's role to gently intervene, challenge, and funnel ideas toward a scientifically accurate explanation (Mortimer & Scott, 2003). To help pre-service teachers develop a cohesive understanding of the key features of managing science classroom discussions, I have them examine video cases from the 'Ambitious Science Teaching' site and TIMSS video study site (Ambitious Science Teaching, 2015; TIMSS, 2016). Before starting the lesson, pre-service teachers are asked to bring in a brief transcript of a lesson excerpt from one of the videos and discuss what the teacher's purpose is with the discussion and how it supports meaningful learning. Often, I provide the entire class with one video to examine, so we all have watched the same high school lesson.

During our lesson, I ask pre-service teachers to share their excerpts in small groups and discuss the ideas. We then start presenting the ideas as a class, and I ask some pre-service teachers to start recording our thoughts. I have found that pre-service teachers are often adept at finding excerpts that I would also identify. The key to the lesson is to operationalize what is happening during teacher/student discussions. In many cases, I will find the video segment associated with the transcript and we will watch it together during our discussion.

In the section below, I share excerpts that pre-service teachers have identified from an Earth Science teacher's lesson on different types of rocks for a grade 8 class on the TIMSS video study site (TIMSS, 2016). This video and full transcript is publicly available to anyone once they register for access. I have found it to be very useful to help pre-service teachers map the excerpts to core science teaching practices articulated by Mark Windschitl and colleagues at the University of Washington (Ambitious Science Teaching, 2015).

Eliciting Students' Ideas

One central theme that pre-service teachers point out is that the Earth Science teacher called particular students' names when posing questions to the class, as opposed to allowing just any student to respond. He also tended to call on at least two students before continuing on with his own thoughts. In the example transcript below, the teacher has shown his students a column full of sediment, and has asked how a person would know they are looking at sedimentary rock.

Teacher: My question is, how are you gonna spot it, how are you gonna identify it when you see it? There's a lot of roads that are cut from sedimentary rock, and you can see it if you know what to look for. What's that, Samuel?

Samuel: When it- certain rocks might have layers on it.

Teacher: Oh. Let's see. [Quickly presents a picture of the Grand Canyon] Like that?

Samuel: Yeah.

[The teacher goes on to ask other students to express their ideas]

Teacher: Nikita, how do you know? How do you know? How do you know, Nikita? Look at it.

Nikita: Because it's stuck together.

Teacher: How do you know it's stuck together?
Nikita: Because it's in layers.
Teacher: Say that.
Nikita: Because it's in layers.
Teacher: Okay.

The teacher consistently displays patience with allowing students to express their ideas during this discussion. We link this lesson excerpt to the science teaching practice of 'eliciting students' ideas.' We then discuss why this would be an important practice to employ during a lesson. Pre-service teachers eventually highlight ideas associated with diagnosing students' knowledge and checking understanding.

Working on Students' Ideas

As the lesson unfolds, it is clear that the teacher has been discussing sedimentary rocks with the class, and now he wants them to consider other types of rocks. In the excerpt below, the teacher shows a picture of him standing on a volcano in Hawaii.

Teacher: Why do I have to be standing on another kind of rock that we're gonna call non-sedimentary at least for the time being? Why?
[The students discuss ideas associated with heat and magma].
Teacher: What has to happen to magma, or in other words, molten rock- that's where the heat comes in- in order for it to become solid? Think about it.
Student: It has to cool.
Teacher: That's right. So if magma cools, it becomes solid, much the same way that when water cools it becomes ice. And what kind of rock is this non-sedimentary rock? It doesn't come from sediments. What is it, Terrence?
Terrence: It's igneous rock.
Teacher: Very good. So there's another type of rock.
[Some further discussion on igneous rock.]
Teacher: How does igneous rock form? How does it form, Kyra?
Kyra: Igneous rock is formed when magma cools.
Teacher: Can't hear.
Kyra: Igneous rock is formed when magma cools.
Teacher: [writes Kyra's claim on the board]. Now, when magma cools, what happens to the state of matter that it's in? There's a change in state of matter?
Kyra: Yeah.
Teacher: Yeah. So what's the change, Rudy?
Rudy: From liquid to solid.
Teacher: [Teacher adds Rudy's idea to Kyra's]. Okay. So it becomes solid so we could say it solidifies. There you go.

In this excerpt, after the teacher elicits students' ideas about magma, he then transitions to asking them to connect the role magma to the formation of igneous rock. As is typical with this instruction, he always asks students to develop an explanation, and records their answers together on the board. In this excerpt, we discuss the principle of 'working on students' ideas,' meaning that it is the role of the teacher to ask students challenging questions to clarify their thinking, as well as help synthesize the explanations. This approach to science instruction helps create a community atmosphere in which everyone can be involved with the developing scientific story.

Pressing for Evidence

After the teacher helps students distinguish between sedimentary and igneous rock, he then asks students to consider observational cues to support the idea that they are indeed examining igneous rock. This is demonstrated in the following excerpt.

Teacher: Now, look at this. [Teacher pulls out a large piece of igneous rock and starts walking around the class, showing it to each student] What evidence is there that this is igneous rock? Look at- look at the surface. Look at the surface. Anyone see any evidence? Remember, it was once liquid. [Many students' hands go up].
Student-1: Oh, oh, oh, I know.
Teacher: What do you see there? What do you see, Student-1?
Student-1: It's like- the little holes inside of it.
Teacher: Well, you're right. What do you think the little holes are from?
Students: Bubbles. Bubbles.
Teacher: What kind of bubbles?
Student-2: Magma bubbles or lava bubbles.
Student-3: Oxygen.
Teacher: Well, what makes bubbles?
Students: [Talking over each other] Heat!…Liquid!…Air!
Teacher: Air. Some kind of gas. So when this magma came up through the volcano in Hawaii, the magma that it contained had a lot of gas in it. Guess it was something like club soda, has bubbles in it. So when the rock cooled and solidified-
Student-4: The holes-
Teacher: The holes- yeah. The holes became preserved.

In this excerpt, pre-service teachers often point out that many of the students are raising their hand and wanting to be part of the conversation. The teacher is constantly walking around the classroom, using multiple representations (diagram on the projector, picture on a television screen, and physical rock he is passing around to the students). We consider the fact that the teacher is continuing to work on students' ideas about the connection between magma and igneous rock, but he is also taking it a step further by 'pressing for evidence' to support students' claims. We link this idea of 'pressing for evidence' back to 'working scientifically' outcomes in the NSW syllabus. Students are expected to use evidence as a basis for constructing explanations, and this can be supported by teacher questioning.

The benefit of this lesson is that it helps them see a common teaching practice – managing discussions – as a complex set of moves working toward well-designed curricular objectives. I have found that taking the time to analyse video cases of classroom discussions has greatly improved the pre-service teachers' planned questions for their own 5E lessons in assignment #2 (explained below).

ASSESSMENT

There are only two assessments in the course, and each is worth 50% of the final course grade. The purpose of the first assignment is for pre-service teachers to investigate how students think about a particular topic, and use that knowledge to design a diagnostic assessment and exploratory activity that could be implemented in a secondary classroom. The first assignment serves as a scaffold for the 2nd assignment. Whereas the first assignment is essentially asking them to develop instruction for the Engage and Explore phases of a 5E unit, the 2nd assignment asks them to design an entire 5E unit for a different science topic (lasting at least three secondary-level lessons, where lesson 1 might include the Engage and Explore phases, lesson 2 might continue the explore phase and complete the Explain phase, and lesson 3 might include the Elaborate and Evaluate phases).

Assignment 1: Connecting Prior Knowledge to Exploratory Experiences

There are three tasks to complete in assignment 1. First, pre-service teachers develop and facilitate a short interview with a secondary-aged student about his/her understandings of a science concept from the NSW syllabus. With this exercise, pre-service teachers learn to present the student with a natural-world phenomenon that the concept explains. For example, for the topic of mitosis, rather than asking the student what she knows about this topic, the pre-service teacher might present a scenario asking the student to explain what is happening when a plant root grows in length over time. They also learn to listen and record students' thoughts without intervening or evaluating them. For the second task, pre-service teachers explore the science education research literature, seeking information regarding how students think about their topic. For the third task, pre-service teachers are required to draw upon what they learned from their student interview and examination of literature to design an introductory assessment and exploratory activity. With the example of mitosis, a pre-service teacher might learn from her interview that a student believes cells grow larger in size but not in number, and then find out from her literature search that other students are prone to believe the number of chromosomes reduces in half for each occurrence of cell division (Riemeier & Gropengieber, 2008). The pre-service teacher might then develop a diagnostic assessment with a set of concept cartoons with potential answers tied to commonly held misconceptions related to cell division, as well as a laboratory activity in which students examine cell division in onion root tips. The pre-service teachers are required to include scaffolding questions to help confront students' alternative ideas during the activity (e.g. asking students if there is evidence of cells continuously growing larger or if the number of cells increases due to division).

Assignment 2: Developing a 5E Instructional Unit

For the 5E lesson series, pre-service teachers learn early in the course that submitting a random collection of activities related to a topic will not earn them a passing grade. Rather, they must design and incorporate activities that work together in a constructivist sequence, with supplementary teaching materials that support student learning in each phase. They are then asked to write an essay justifying their selection of activities and how they align to each 5E phase. Pre-service teachers often find this to be a daunting task at first. However, I build in time during class throughout the semester for them to work on sections of each assignment and receive peer and instructor feedback (see Table 1). The feedback sessions in class serve to reinforce our communal understanding of the 5E model and challenge each other to design engaging and authentic activities. Together, the assignments provide opportunities for pre-service teachers to formalize their understandings of lesson planning, the core learning principles, and constructivist science teaching.

CONCLUSIONS

The 5E model is certainly not the only reform-based approach to science instruction, and there are plenty of other models that are equally valid and research-supported (a point I discuss openly with my pre-service teachers). So why do I continue to advocate for the 5E model? For any course, the reality is that we must prioritize certain objectives over others. As to which content we conclude should be debated in the science teacher education literature, but most important to me is that the pre-service teachers feel they learned a few big ideas meaningfully rather than a large number of ideas superficially. Given that our pre-service teachers enter with such robust orientations for didactic, rote science instruction, I think one of the best outcomes I can achieve in this course is to confront those orientations and develop their practical knowledge for teaching with an alternative model. Moreover, I see my focus on the 5E model as a practical approach to improving the state of science teaching in NSW. It is a model that many teachers are aware of through professional development initiatives. While I believe the use of constructivist sequences of instruction is not quite as prevalent as we might hope for in NSW, many teachers do occasionally incorporate the 5E model and are aware of its goals. Thus, the model is well known enough to provide a basis for common communication between pre-service and mentor teachers and yet not utilised enough to make it an important aim for my science methods courses. The advantage of focusing on the 5E model in depth as opposed to surveying a large number of models is that pre-service teachers walk away with stronger beliefs and practical knowledge for utilising this type of instruction in secondary contexts. Moreover, designing the course as one large 5E unit has provided coherence for pre-service teachers and supports their learning of key principles and practices for teaching secondary science.

A disadvantage of the course design as it currently stands is the lack of explicit integration between the course and pre-service teachers' professional experience placements. There are concerns about overloading the pre-service teachers with assignments as they complete their 6-week intensive teaching experiences at schools, as they must acclimate and begin teaching in a unique context very quickly. However, I am now piloting the use of small-scale reflection tasks that link back to the 5E model, which pre-service teachers complete throughout the school placement as part of Assignment 2, which is then submitted at the conclusion of the school experience. Such a design has great potential to more purposefully close the theory/practice gap in science teacher education.

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3. INTERDISCIPLINARY SECONDARY SCIENCE METHODS

A United States – Massachusetts Context

INTRODUCTION – CONTEXT

Reforms in science teaching and learning in the United States (U.S.) date back to Sputnik and the race for space (Bybee & McInerney, 1995; NCEE, 1983; National Science Board, 1983). During this time, the U.S. began to emphasize science and mathematics more in schools and later included engineering and technology to what is now known collectively as STEM – for Science, Technology, Engineering, and Mathematics (Bybee, 2013; NRC, 2011). What STEM looks like in practice, however, remains an area of investigation (Campbell, Witzig, Welty, & French, 2014). In the late 1980s and early 1990s, scientific literacy was pushed as a driving force in science teaching. The idea is that we needed all citizens, regardless if they were going to pursue careers in science, to understand, and be knowledgeable consumers of advancements in science (Rutherford & Ahlgren, 1990). In 1996, the *National Science Education Standards* were put forward which shaped science instruction in K-12 schools (NRC, 1996). There was new emphasis placed on hands-on inquiry-based learning and led to a follow-up document in 2000, *Inquiry and The National Science Education Standards* (NRC, 2000). These national documents shaped the development of state standards documents. For example, in 2006, Massachusetts updated and published the MA Science and Technology/Engineering (MA STE) Curriculum Frameworks (MA DESE, 2001/2006). In addition to science content, emphasis was placed on inquiry, nature of science and the integration of technology and engineering in science. While inquiry-based teaching was being adopted by K-12 teachers in science, how inquiry was being interpreted varied greatly. This led to decades of professional development for teachers on what constitutes inquiry-based teaching steered by considerable research on reform and inquiry-based teaching in science as well as how people and students learn (Bransford, Brown, & Cocking, 2000; Sawada et al., 2002). Learning cycle frameworks, like the 5E model, were heavily promoted to science teachers as organizers for classroom (Bybee et al., 2006). The next wave of reform efforts in science education was the development of learning progressions (see Alonzo & Gotwells, 2012). The premise here was to identify major science concepts and develop vertical progressions of learning throughout the grades to build on prior knowledge. This began to reshape how science was

A. J. Sickel & S. B. Witzig (Eds.), Designing and Teaching the Secondary Science Methods Course, 33–52.

being taught in schools and set the groundwork for the development of new national standards (NRC, 2007). In 2012, the *Framework for K-12 Science Education* was developed as a guiding document for a reconceptualization of new National science standards (NRC, 2012). The *Next Generation Science Standards* (NGSS) placed emphasis on three dimensional (3D) teaching and learning: (1) disciplinary core ideas, (2) science and engineering practices, and (3) cross-cutting concepts (Achieve Inc., 2013). Many states adopted NGSS while others used them as a guide to revise their existing state standards. While MA was one of the lead states that helped to draft NGSS, the decision was ultimately made not to adopt them in favor of adapting them as an updated MA STE Curriculum Framework (MA DESE, 2016). The cross cutting concepts dimension was de-emphasized and the disciplinary core ideas and practices were merged into singular statements as learning standards for students. The design for curriculum and instruction based on the standards was not mandated by the new state standards.

> The standards are outcomes, or goals, that reflect what a student should know and be able to do. They do not dictate a manner or methods of teaching. The standards are written in a way that expresses the concept and skills to be achieved and demonstrated by students, but leaves curricular and instructional decisions to districts, schools, and teachers. The standards are not a set of instructional activities or assessment tasks. They are statements of what students should be able to do *as a result of* instruction. (MA DESE, 2016, p. 20)

Many MA school districts are currently rolling out the new MA STE standards as they develop curriculum and as new statewide science assessments are developed.[1] In parallel to the development of reform based K-12 standards documents, the preparation of science teachers in the U.S. kept pace with preparing teachers to implement each new wave of reform. Below I share the details about the science teacher preparation program at the University of Massachusetts Dartmouth (UMassD).

At UMassD, science teacher candidates enroll in a 33-credit masters program across 11 courses (3 credits per course, 3 contact hours per week). The masters program is a full time 2-year program where candidates earn a Masters of Arts in Teaching (MAT) and an initial license in their respective content area (Biology, Chemistry, Physics, or General Science). In addition, we have an accelerated masters program where undergraduate science students can apply for and begin taking graduate education courses in their junior year, allowing them to finish with a bachelors of science (BS) in their science content area and an MAT with an initial license (4+1 BS-MAT program). Our masters program is typical of many of the teacher preparation programs in the state. Due to licensure requirements for teachers in MA, most teacher preparation programs are at the graduate level. MA requires teachers to hold a BA/BS degree, to meet subject matter knowledge requirements in the licensure area they are seeking, and to pass two state-designed teacher licensure exams – MA Tests for Educator Licensure (MTEL),[2] one being in the content area of the pre-service teacher (Biology, Chemistry, Physics, or General Science) and another focused on general communication and literacy skills, to earn their initial teaching license. While some undergraduate specific programs do exist in MA, teachers are required to advance their initial license to a professional license in their first 5 years of teaching requiring a masters degree and additional content courses. Therefore, coupling the initial license with the MAT degree saves teachers coursework later, and allows them to enter the profession on day 1 already with a MAT. Teachers then can focus on science specific education courses to advance their license to professional while teaching. The sequence of courses for our MAT initial licensure program is depicted below in Table 1.

In each of their first three semesters, science pre-service teachers (PSTs) take three graduate education courses. While enrolled in coursework, PSTs are engaged in three separate 30-hour pre-practicum experiences in secondary schools and classrooms. The focus of each of these pre-practicum experiences is meant to align with the coursework and to scaffold experiences for PSTs to prepare them for their student teaching semester (semester 4), and for their first year as a new teacher.

In each of the courses comprising the 33-credit MAT, as well as through reflection during the 90 hours of pre-practicum experiences during the first three semesters, PSTs come to learn and understand pedagogical and professional skills that MA has prioritized as important for all teachers to possess. These skills in MA are known as MA Professional Standards for Teachers (MA DESE, 2015). These include:

Table 1. Course sequence for science MAT initial licensure program

Semester	*Course Name*	*Credits*
1	EDU 510: Psychological and Social Foundations of Education	3
	EDU 511: Culturally Responsive Curriculum & Instruction	3
	EDU 519: Technology & Instruction	3
	Pre-Practicum 1: Focus on School Structure (30 Hours)	
2	EDU 512: Teaching and Managing Inclusive Classrooms	3
	EDU 518: Assessment for Instruction	3
	EDU 525: Critical Literacies	3
	Pre-Practicum 2: Focus on Teacher (30 Hours)	
3	EDU 552: Sheltered English Immersion	3
	EDU 513: Critical Issues in Education	3
	SCI 541/581: Secondary Science Methods	3
	Pre-Practicum 3: Focus on Students (30 Hours)	
4	EDU 532: Student Teaching Practicum Middle/Secondary	3
	EDU 533: Student Teaching Practicum Seminar	3
	Total Credits:	33

- Curriculum, Planning, and Assessment standard: Promotes the learning and growth of all students by providing high quality and coherent instruction, designing and administering authentic and meaningful student assessments, analyzing student performance and growth data, using this data to improve instruction, providing students with constructive feedback on an on-going basis, and continuously refining learning objectives.
- Teaching All Students standard: Promotes the learning and growth of all students through instructional practices that establish high expectations, create a safe and effective classroom environment, and demonstrate cultural proficiency.
- Family and Community Engagement standard: Promotes the learning and growth of all students through effective partnerships with families, caregivers, community members, and organizations.
- Professional Culture standard: Promotes the learning and growth of all students through ethical, culturally proficient, skilled, and collaborative practice. (MA DESE, 2015, pp. 4–6)

Each of these four professional standards for teachers has a series of indicators within the standard and a corresponding the level of practice a PST would be responsible for before being licensed – from 'introduction' to 'practice' to 'demonstrate'. These standards are aligned to the MA educator evaluation framework to ensure that beginning teachers are prepared for their first year of teaching.[3]

In semester 3, PSTs take their science methods course. We offer two different science methods courses – 1. *SCI 541: Methods and Resources in General Science for Middle School Educators* and, 2. *SCI 581: Methods and Resources for Secondary Science Educators*. SCI 541 is for future general science teachers in the middle grades, whose initial license is valid to teach grades 5–8 (though typically in MA, the middle grades are grades 6–8). SCI 581 is for future high school science teachers, whose initial license is valid to teacher grades 9–12 in their respective science discipline – Biology, Chemistry or Physics. However, due to enrolment numbers, these two science methods courses are typically combined and taught as one interdisciplinary science methods course. This course is purposefully placed in PSTs third semester to allow them to build on prior general pedagogy courses. They come to the science methods having an understanding of the psychology of education and how students learn, how to foster culturally responsive teaching, how to teach inclusive classrooms, how to incorporate technology in instruction, and the role of the assessment in teaching and learning among other critical skills and competencies necessary for new teachers. In the science methods course, they put all of these skills and competencies into practice in a discipline-specific manner. They learn discipline-specific strategies to teach all students and practice through the development of lesson and unit plans and through micro-teaching. The course is structured to help prepare PSTs for their semester long student teaching practicum (EDU 532) in a science classroom in one of our local partner districts under the direction of a university supervisor and a supervising practitioner in the school. Paired with EDU 532, PSTs enroll in a student teaching practicum seminar (EDU 533) where they reflect on their experiences in the science classroom and in the partner school. The purpose of this seminar is to provide a structured experience for learning and refining the theories and practices necessary to become an effective science teacher of all children in inclusive content specific classrooms. Below I detail the planning and design of the secondary science methods course at UMassD that occurs in semester 3 of a science PST's program, the semester before they are in the field full time during their practicum.

PLANNING – SECONDARY SCIENCE METHODS COURSE DESIGN

Given that there is only one secondary science methods course that PSTs take in their MAT program at UMassD, considerable planning was necessary to ensure that PSTs are prepared for their subsequent student teaching practicum semester as well as when the enter the science classroom as a teacher of record. The science methods course is designed to integrate four important aspects of teaching science in the school: becoming a reflective practitioner, gaining knowledge of oneself as a learner of science, gaining knowledge of oneself as a teacher of science, and gaining knowledge of children. The science methods course prepares one to craft a science teaching practice that reflects current educational research, philosophies, and methodologies. MA Department of Education subject matter knowledge requirements are developed via reflection on research/practitioner articles as well as through learning experiences both in and out of the classroom. PSTs implement, evaluate, and reflect on instructional strategies unique to school science teaching. We have developed the science methods course at UMassD so that PSTs can use course content and experiences to develop the following nine critical outcomes:

1. An understanding of recent trends in science education policy and goals;
2. An awareness of the diversity of curricular approaches available to school science educators, including environmental, inquiry, and interdisciplinary curricula;
3. An ability to design lessons and units that are developmentally appropriate and sensitive to the needs, values, and interests of a diverse group of science students;
4. An ability to construct assessment plans that are compatible with teaching goals and methods and that allow for multiple ways of representing knowledge;
5. An ability to use diagnostic observation skills, instructional strategies to promote science learning in small group or whole-class settings;
6. An ability to use multimedia technologies to support meaningful learning;
7. An awareness of organizations and resources (human, environmental, and technological) that serve the professional development of school teachers;
8. An ability to establish rules and procedures that ensure the physical safety of children; and,
9. An understanding of reflection in professional development and lifelong learning.

Table 2. Overview and sequence of science methods course topics and assessments

Weeks	*Theme/Topic/Readings*	*Assignment (Complete prior to class)*
1	• Introductions and introductory NOS activity (New Society) • Lesson Planning Task – Pre-assessment • Syllabus review *Readings/Assignments:* Nature of Science (NOS) focused readings, Teaching card sorting task	
2	• Science Teaching card sorting peer interview • NOS Discussion (working definition/understanding of NOS) • Development of a list of goals for Secondary Science (RBF and Standards precursor) • Introduction to MA and National Standards documents *Readings/Assignments:* MA & National standards documents	RJ1, Card Sort Task
3	• Student Investigation I (Model engagement with 'learner hat') • Discussion of to MA and National Standards Documents *Readings/Assignments:* Instruction focused readings, RBF intro	RJ2
4	• Student Investigation I continued & presentations • Reform-based instructional observation indicators discussion • PT 1 Planning *Readings/Assignments*: Learning Cycle Framework readings	RJ3, RBF1
5	• PT 1 Planning Continued • RBF II Discussion and planning *Readings/Assignments:* Core Instructional Practices	RJ4, SI1
6	• Instructional practices discussion • PT1 Teaching (Groups of 2) *Readings/Assignments*: Science teacher knowledge	RJ5, PT1
7	• Science teacher knowledge discussion • Student Investigations II planning *Readings/Assignments:* Science teacher knowledge II	RJ6, RBF2
8	• Science teacher knowledge discussion continued • Student Investigations II continued *Readings/Assignments:* Science teacher knowledge III	RJ7
9	• Student Investigation II presentations • PT 2 Planning (Individual) *Readings/Assignments:* Science Practices – Modelling	RJ8, SI2

Table 2. (Continued)

Weeks	*Theme/Topic/Readings*	*Assignment (Complete prior to class)*
10	• PT 2 (work session) • Science Safety Module intro *Readings/Assignments:* Science Safety Modules; reading on topic for PT 2	RJ9
11	• Science Safety Discussion • PT 2 Teaching (Individual) *Readings/Assignments:* Science Practices – Argumentation	Science Safety, RBF3
12	• Unit Planning Intro, Topic Determined • Unit Planning (Work Session) *Readings/Assignments:* Socioscientific Issues based education	RJ10, PT2
13	• Discussion of Socioscientific Issues based education • Unit Planning (Teaching Session): Presentations of unit plans	Unit Plan
14 Finals	Finals Week Exit Interview: Meeting to share final RBFs and complete post-Assessment of ideas about teaching and learning science	RBF4, Pre-Practicum Field Journal

RJ = Reflective Journal; RBF = Research Based Framework; SI = Student Investigation; PT = Pedagogical Transformation lesson plan.

Each of the outcomes are reached through a myriad of course activities and experiences spread across the 14 week semester. Table 2 provides an overview and sequence of the course topics, readings, and assessments.

I begin the science methods course each semester with introductions – I want the students to know who I am as well as know a little something about each of their classmates. This discussion, while taking a considerable amount of time during the first session, sets a precedent in the course that the course will be interactive and discussion based. Following introductions, we engage in a beginning of the semester activity known as the *New Society* (Cavallo, 2008). Briefly, a subset of students is put on a mission as scientists/explorers to determine as much as they can about a new society that they have just discovered (the remaining classmates). However, what the scientists do not know is that the new society lives by three rules that they must uncover through investigation. This activity serves two purposes in my science methods course: (1) It serves as a primer for a discussion about nature of science (NOS) that continues throughout the semester, and (2) It establishes a classroom culture where students are up out of their seats, engaged in scientific investigations – modelling this for PSTs is important and research-based.

After the *New Society* activity, I ask the students to develop a two-day lesson plan that introduces a topic to meet a MA State science learning standard following specific prompts as a pre-assessment. I ask students as they develop their lesson to provide as much detail as possible and to consider the following: What are your goals for the lesson and what do you want the students to learn? Describe what will happen during the beginning, middle, and end of each class – What will you do? What will the students do? In addition, they should include details about what comes before/after this lesson; how they will find out what students know; how their lesson will help students understand what science is or how science is done; and how they going to get students to think and act like scientists. Since lesson and unit planning (described below) are key aspects of this class, I use this a pre-assessment to gauge what the PSTs currently know about designing science instruction to inform my own instruction. We revisit these initial lesson plans throughout the semester during discussions of the readings and course activities as well as during the exit interview I schedule with each PST in the last week of class (the exit interview is described more below). Before the end of the first class, I distribute a secondary science based card-sorting task (adapted from Friedrichsen & Dana, 2003). This task asks students to reflect on 20 different science teaching scenarios and asks them to reflect on whether they represent how they would teach or do not represent how they would teach. There are no right or wrong answers to this assignment, but PSTs orientations to teaching become evident in their reflections about each of the scenarios.

Reading are assigned each week and structured to align with the course discussion and course activities. PSTs are expected to read all of the assigned material and write a 1–2 page reflective journal of their thoughts on the readings. These reflections are not a summary of the reading, but a synthesis of the readings and experiences throughout the course and how these are shaping the PSTs thinking about teaching and learning in science. These reflections are encouraged to be around ideas that PSTs are still considering, and may not have a complete understanding of. The reflective journals (RJ) are due each week and drive the subsequent class discussion (Table 2).

The readings are updated each time the class are offered, though typically center around the following themes: NOS (Lederman & Lederman, 2014; McComas, 2004), MA and National standards documents (MA DESE, 2016; NRC, 2012; Achieve Inc., 2013), science instruction (NRC, 2007), learning cycle frameworks (Bybee et al., 2006), core instructional practices (Windschitl, Thompson, Braaten, & Stroupe, 2012), science safety,[4] science teacher knowledge – including an understanding of pedagogical content knowledge (PCK) (Abell, 2007; Magnusson, Krajcik, & Borko, 1999), science practices (Achieve Inc., 2013; Hunter, 2015; Raven, Klein, Namdar, 2016), and socioscientific issues based education (Presley et al., 2013; Witzig, Halverson, Siegel, & Freyermuth, 2013). I choose readings around these themes based on current understandings of research on science teaching and learning – topics that I believe are important for future science teachers to have some exposure and experience with. Our discussions of the readings in class are aimed at encouraging the PSTs to reflect on their current understanding of science teaching and learning (through their past experience as a learner or their experience in science classrooms during their pre-practicum placements) and to situate the ideas from the readings in way that has them reconsider what is possible in the science classroom – to push their thinking in ways that they may not have gone without being exposed to these new ideas.

PSTs are engaged as K-12 learners in the science methods course during two student investigations. These are opportunities for PSTs to reflect on instructional decisions made by a teacher (me as the instructor of the course) and to use these to model their own student investigations (as future science teachers). More detail is provided on the student investigations below in the "classroom practice" section.

Throughout the semester, PSTs are asked to develop their own research based teaching framework (RBF). This begins with them reflecting on mission and goals statements in the MA and National standards documents and using these as guides for them to create their own goals for secondary science teaching. The goal statements are refined and developed into a framework throughout the semester as PSTs are exposed to new ideas, experiences, and research about science teaching and learning. I use this strategy so PSTs take ownership of their teaching and to incorporate what they have learned throughout the course into a framework that defines who they are as science teachers. I also share with them how much thought and planning I put into the design of the science methods course – I model for them how I strive to meet goals I set for the course, and explicitly state throughout the course the rationale for my instructional decisions. Teaching, and planning for teaching, is a complex endeavour and I use this RBF assignment to help the PSTs ground their decisions as future science teachers in the current research on science teaching and learning. This provides them an anchor for their instructional decision-making while helping them to realize that their framework is a living document they will update as they read, teach, and reflect throughout their careers.

The culminating assessment in the course is the comprehensive unit plan, described in more detail below in the "assessment" section. This assignment builds from two separate pedagogical transformation (PT) lesson plan assignments where PSTs choose a MA learning standard to create a sequence of instruction. PSTs are encouraged break down the core concept in the standard creatively in ways to meet students where they currently are in their understanding of the concept and to get them to connect the concept to the world around them. It is through on-going assessment with conceptual connections to student's lives that help students make meaning of the science they are engaged with.

During the last week of the course, I schedule a 1-hour exit interview with each PST in the science methods course. During this interview, PSTs share their final RBF and I ask them to reflect on what they have learned in the class. I revisit the initial lesson plan that PSTs created on the first day of the course and ask them if they would do anything different than they originally planned. Finally, I revisit the card-sorting task that was discussed in the second class session and ask PSTs to reflect again on these scenarios. It is interesting to learn how PSTs respond to these scenarios after having engaged in various activities and discussions throughout the science methods course. To articulate an example of how science PSTs ideas can change throughout the methods course, Luke, reflected on why he initially (during the first class session) sorted the teaching scenario cards as he did (Witzig & Campbell, 2015):

> *The most populated group represents what I do, and I do so with equal attention and distribution across units. These practices have in common a more teacher-centered approach, or learn first before engaging in activity.*

We characterized Luke's science teaching orientation at the beginning of the course as both 'didactic' (teacher presents information, generally through lecture or discussion… and holds students accountable for knowing the facts produced by science) and 'activity driven' (students participant in "hands-on" activities used for verification or discovery) (Magnusson et al., 1999). During Luke's end of course exit interview he responded about how he would teach science as:

> *So always something different. Small groups I think are important and I like them to discuss things with each other to bounce ideas off of each other, and this lines up with what we learned this semester. I think about them debating and sort of hashing it out and trying to share ideas and at the same time educate each other and let me, uh, get in there with them and try to set them straight and congratulate them when they're right and maybe, give them a little help to steer where they need to be when they're wrong.*

We characterized Luke's end of course orientation as 'guided inquiry' (the teacher and students participate in defining and investigating problems, determining patterns. . .The teacher scaffolds students' efforts to use the materials and intellectual tools of science, toward their independent use of them) and, although much less so, 'didactic' (Magnusson et al., 1999). As evidenced by Luke's shift in responses throughout the semester, I typically find that even a single science methods course can be a transformative experience for PSTs.

CLASSROOM PRACTICE – WHERE DOES ALL OF THE MASS COME FROM?

The environment I try to create in my science methods course is one were pre-service teachers are comfortable sharing ideas, interacting with one another, being open to new approaches, and always reflecting on practice. As mentioned above, as part of the course, I engage PSTs in two "student investigations." The overall goal of these student investigations is for the PSTs to engage in the content with their science 'learner hat' on. That is, I model the investigation as if they are secondary science students and I am their secondary science teacher. Periodically, we will break from these roles to discuss the instructional moves that are occurring and break down and reflect on why these decisions are being made. These breaks are explicit and the PSTs are aware they are shifting between engaging in the lab wearing their 'learner hat' and their 'teacher hat'. For the purpose of illustrating an example of what this looks like in my classroom, I will now share my thinking, planning, and teaching strategies for the first student investigation I engage PSTs in. This begins on our third class meeting, and concludes on our fourth class meeting.

Pre-Investigation Discussion

To begin, I ask the PSTs to stand up from the laboratory benches and walk with me to the classroom window. I ask them to look out of the window at the trees growing in the yards of the houses across the street. There are young/small trees in the front yards, and trees in the back and sides yards that tower over the two and three story houses. While looking at these trees, I then proceed to hand each PST a few seeds to hold and pose the following question: "Trees start off as tiny seeds. Where does all the mass come from?" (Figure 1).

Figure 1. Where did all the mass come from? A view from the science teaching classroom of the trees towering over two and three story houses

Usually there is a PST that wants to blurt out an answer, but I ask them to keep their thoughts to themselves for a minute to allow others to think. When they share their responses, each time I have done this investigation, the first response is invariably "the soil", followed by "water", followed by "nutrients", then the "sun", and it takes some time to for someone to say the "air" or "carbon dioxide (or CO_2)." I ask the students throughout this discussion, and once we have a list generated, to explain a bit more about what they shared, and what their classmates have shared, and how each of these would contribute to the mass of the tree. There is typically uneasiness in this discussion, as PSTs grapple with words to explain the process of photosynthesis. Eventually, this leads to a consensus answer where we discuss that the majority of the mass of the tree comes from a gas in the air – CO_2 through the process of photosynthesis where CO_2 is taken up by the leaves and with water and energy from the sun is converted into sugar with oxygen as the by-product.

The design of this pre-investigation discussion is purposeful. It is meant to expose known misconceptions about photosynthesis (Haslam & Treagust, 1987), including that the mass comes only from nutrients/water in the soil – that it couldn't possibly come from a gas in the air that that is all around us. We switch hats and transition from a discussion as learners to a discussion as teachers. I ask the PSTs why they think I started the lesson in this way? This acts as springboard to discuss the importance of starting a lesson by assessing what students know, what language they bring to the classroom around science topics (did they say carbon dioxide, or C – O – TWO, or gas, or air, etc.), being aware of known mis/alternative-conceptions, and teaching for conceptual understanding in science (Konicek-Moran & Keeley, 2015; Witzig et al., 2013).

Photosynthesis Simulation Laboratory

Following the pre-investigation discussion, the PSTs return to their role as secondary science learners as they engage in a photosynthesis investigation. The investigation is a simulation laboratory[5] where PSTs work in small groups to address the following problem/driving question: "What do plants need to grow, what do they produce, and what environmental factors influence photosynthesis?" They are given access to the simulation (either working on their personal laptops, or on the classroom computers[6]) and are told to explore the variables built into the simulation (Figure 2) while answering a few questions that are meant to be a review of the pre-investigation discussion (*What does a plant need to grow?, What does a plant produce?*) and to make sure they understand aspects of the simulation (*When the plant is bubbling, what is it doing and what gas is found in the bubbles?).*

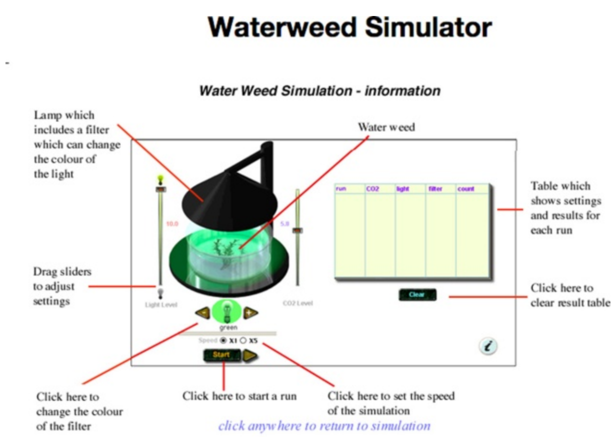

Figure 2. A screenshot of the simulator controls

Once the PSTs are comfortable with the simulator controls, they are asked to develop, in their groups, a hypotheses or research question that they can investigate using the simulation. They need to write out their hypothesis/research question and then design a series of simulator trials that can used to test their hypothesis/research question writing out their materials and procedures. I ask that they check in with me before proceeding to ensure that we have variability in the design of the various investigations. However, with a class full of PSTs this is typically not a concern and with a little guidance and refinements, they are set to collect their data.

While the PSTs are collecting their data, I circulate around the room, answering questions and encouraging the groups to begin to make sense of the data. Following data collection, I ask that they students come prepared for the next class with visual representations of their data and to bring enough copies to share with the other groups in the class. In the following class, we discuss the data, look for trends, discuss group ideas about reflection questions that were posed, and begin to come to class a consensus on factors that influence photosynthesis.

With data collection complete on day 1 of the investigation, PSTs are then asked to engage in a discussion, as science teachers now, about instructional decisions that were made throughout the laboratory. We breakdown and critique my instructional moves, why they thought I made certain decisions, and discuss the pros and cons of using simulation labs in the science classroom. This discussion makes explicit how I modelled the investigation as the secondary science teacher (with them as learners), and how they can modify the lesson to use in their future science classrooms (using this investigation, a difference simulation, a wet lab to investigate photosynthesis, or some other discipline specific investigation to engage students).

I wrap up discussion on day 1 of this investigation by showing a short excerpt from the *Minds of Own* video series,[7] "*Lessons From Thin Air*." The description of the video states:

> Just about everyone will agree that trees are made from sunlight, water, and soil the trees suck up from their roots. But the surprising truth is that trees are made from air! Trees are solar-powered machines that convert air into wood. Why is it that, despite the fact that photosynthesis is one of the most widely taught subjects in science, so few people really understand the central idea underlying this system? Starting with this question, program two explores why something taught in school can go unlearned and shows that we often teach without regard to what children actually need to know.

The section of the clip that I use shows Harvard and MIT graduates, on graduation day, being asked the same question that I posed to my PSTs to start the investigation. The graduates are given a seed, and then a log from a tree, and asked where all of the mass comes from. Viewing and discussing this excerpt drives home the importance of starting a lesson with a well-known mis/alternative-conception. This also invariably makes the PSTs feels better that they did not have a complete understanding of the “big idea” of photosynthesis. Furthermore, it acts as the starting point of a conversation that will persist throughout the semester in science methods about the importance of what, how, and why we teach science.

ASSESSMENT – UNIT PLANNING AS A COMMON ASSESSMENT

The science methods course culminates in a comprehensive instructional unit plan. The unit plan has been established to be a common assessment across all of the methods courses (science, mathematics, English, history, and foreign language) in our teacher preparation program and is structured based on Wiggins and McTighe’s (2005) backward design model. The unit plan is used not only as evidence in a students teaching portfolio to assess their preparation in the discipline, but also as evidence for us as a faculty to assess the effectiveness of our program. Here I will walk through the progression and scaffolding that is provided to set our science methods PSTs up for success as new teachers.

The comprehensive instructional unit plan in the course is required to contain several key elements and to be clearly aligned to the MA STE Curriculum Framework (MA DESE, 2016). The sequence of instruction for the unit should span 5–10 days; there should be an explicit explanation of how the instructional unit meets the needs of diverse learners; an assessment plan including formative and summative assessments which elicit and provide evidence for student learning should be clearly identified; science safety precautions important in facilitating each day of the unit should be clear; there should be clear description of the learning activities and how technology recourses are utilized; and there should be a clear demonstration of the PSTs’ professional preparation as indicated by the MA professional standards for teachers (MA DESE, 2016). Table 3 depicts the rubric used to assess the unit plan.

PSTs develop their unit plan in stages across the semester beginning with two separate lesson plans. In science methods, these lesson plan assignments require students to grapple with the idea of pedagogical transformations as defined by Oh & Oh (2011) as “the instructional principle in which scientific ideas are simplified and reconstructed into what can be readily accessible to an understood by students without distorting the essential features of the ideas” (p. 1124). Early in the semester, students are introduced to the learning cycle literature (Bybee et al., 2006; Table 1) and in prior work, myself and a colleague surveyed the research literature on science teacher preparation programs and developed a working research-based teaching framework as a guide for a science methods course (Witzig & Campbell, 2015). The working framework includes three phases, *Engage*, *Investigate*, and *Constructing Explanations* that are rooted in the learning cycle literature (Bybee et al., 2006). These phases are aligned with the scientific practices in the new science education framework and NGSS (Achieve Inc., 2013; NRC, 2012) and are designed to help students move from everyday understandings of science concepts to a more scientifically accepted understanding (Lemke, 1990; Mortimer & Scott, 2003).

Table 3. Comprehensive unit plan rubric

Category	*Rating*				*Comments*
Subject & Grade level are clearly indicated	3	2	1	N/A	
Unit encompasses detailed lesson plans to guide 5–10 full days of instruction.	3	2	1	N/A	
Time Allocated (within each day as well as detailed day-by-day) for each activity within each lesson is clearly indicated	3	2	1	N/A	
Content is aligned with the appropriate MA Curriculum Framework and appropriate National Standards – Standards are clearly indicated.	3	2	1	N/A	
Objectives/Learning Goals/Essential Questions are clearly indicated and are aligned to the standards.	3	2	1	N/A	
Includes description of how the individual lessons fit into a larger sequence of instruction	3	2	1	N/A	
Each day of the unit includes specific instruction to meet the needs of diverse learners.	3	2	1	N/A	
Unit contains clear assessment plans including both formative and summative assessment to show evidence of student learning with respect to the targeted standard(s).	3	2	1	N/A	
Learning activities are included with unit.	3	2	1	N/A	
Unit includes Resources/Readings/Handouts (both print & electronic) and references to the source material.	3	2	1	N/A	
Unit contains description of technology resources necessary for instruction and how these will be implemented.	3	2	1	N/A	
Each day of the unit includes a detailed plan for the necessary safety precautions	3	2	1	N/A	
Unit demonstrates student's professional preparation as a teacher as indicated by MA professional standards for teachers.	3	2	1	N/A	
Overall comments:					

Rating Key: 3 = Excellent, 2 = Satisfactory, 3 = Needs improvement, N/A = Not Applicable.

Typical of backwards design, the pedagogical transformation (PT) lesson plan template begins with the PST identifying the lesson topic as well as the corresponding MA STE curriculum standard to be assessed. They then develop a rationale that helps them articulate why this topic is important for students, what they want their students to walk away with knowing (in the form of a driving question), how this lesson fits in with previously learned concepts, and how learning this concept will inform future learning. I then ask the PSTs to research what is known about how students' struggle with the concepts included in the lesson (including mis/alternative conceptions). The PSTs then plan out their instruction for each of the three phases of the framework (*Engage, Investigate, and Construction Explanations*) by describing the activities, the students' role, the teacher's role, the formative assessments they will use to guide their instruction as well the materials needed, a science safety plan, and how they will differentiate instruction. The key for the PSTs is to develop their lesson plans using the idea of pedagogical transformations and this working framework.[8]

PSTs share their lesson plans with the class through micro-teaching which serves both as a formative assessment for them as well contributes to their formal grade as they revise their plan accordingly. They prepare to teach a 15-minute segment of their lesson plan and are peer assessed using a "critical friends feedback" protocol that I use that includes 4 guiding questions for them to comment on for their peers.[9] I also comment on critical friends feedback protocol and provide all of this feedback to the PSTs after their presentation. After writing out the qualitative feedback for each presenter, we have a class discussion de-briefing each of the presentations for the presenters. The purpose here is to provide this qualitative formative feedback to the presenters about their micro-teaching so that they can reflect and make any necessary modifications to the lesson/unit plan that they were micro-teaching from. While this phase is not graded (as summative feedback), it serves as formative assessment for the PSTs. When I review their lesson/unit plans (after they have time to modify as needed), these are graded with detailed feedback provided to serve both as summative feedback for the specific assignment, and formative feedback to consider for future assignments in this class, and for them to consider as they plan lessons and thematic units as a future teacher. I consider their micro-teaching presentations during this summative assessment/feedback. The unit plan ensures that PSTs are able to transform a learning target into an effective learning sequence for students while also ensuring that the lessons reflect the processes undertaken by scientists as they do science.

What I have learned through this assessment over the years is that the PSTs need considerable support in developing lesson (and unit) plans as well in teaching utilizing these plans as guides. Prior to entering the science methods course, they have been introduced to lesson planning in several of their general education pedagogy courses (using backwards design). However, they have shared that they have had limited to no experience in actually teaching the lessons that they have previously developed. Also, while the context for the specific lessons may have been in their respective science disciplines, the nature of the general pedagogy courses is not science specific. This makes it a challenge for the PSTs to put their lesson planning preparation into context until they reach science methods. We continually address this as a faculty as we work to improve the PST preparation throughout their experiences in the program.

CONCLUSION – STRENGTHS AND AREAS FOR IMPROVEMENT

What Works Well

What works well in the format of the interdisciplinary secondary science methods course at UMassD is that PSTs from multiple disciplines – Biology, Chemistry, Physics and General Science – have the opportunity to collaborate and learn from one another while developing discipline-specific knowledge for developing and teaching in their respective content areas. The structure and sequence of the course is purposefully organized to scaffold science teaching and learning experiences for PSTs to prepare them for their own science classroom contexts.

Starting the course off with a NOS discussion allows the PSTs to reference this throughout the course in discussions and to incorporate NOS into their lesson and unit plans as appropriate. The student investigations, while not always in a PST's content area, can be adapted, and at minimum the instructional strategies introduced can be applied. For example, in the photosynthesis investigation, the content is more closely aligned to biology standards. However, digging deeper into the chemistry or physics involved in photosynthesis could allow for this investigation to meet chemistry and physics standards while situating the lesson in a real world context – where does the mass in the trees around us come from? Why is this important for our lives (connections to socioscientific issues), and how does knowledge of chemistry and/or physics help us understand this more? Content aside, drawing from the photosynthesis investigation, this lesson introduces several instructional and assessment strategies that are applicable across science disciplines including assessing prior knowledge, starting with students' everyday language, use of questioning, having students' designing their own investigations, the use (and limits of) simulation labs, and the importance of sharing scientific findings through presentations. Each of these strategies is modelled purposefully for the PSTs in the photosynthesis investigation. It is then the responsibility of the PSTs to incorporate these (and other strategies modelled and discussed in the course) into their own teaching repertoires (including the development of their own RBF). This becomes evident in PSTs' micro-teaching later in the course as they share their lesson and unit plans.

Areas for Improvement

As discussed above, PSTs in our program only have one science methods course built into their program (Table 1). With this in mind, while planning experiences for the PSTs, considerable thought and research went into the course design. Decisions about what to prioritize, and what to (unfortunately) spend less time on weighs heavy on my mind. In the end, I make the decisions that I do based on current research on teaching and learning in science. It is my hope that this book, and research that this book inspires, will continue to shape the decisions I make as I teach future science teachers. With that said, there are some areas of the science methods course, and our program, that I know could be altered to help better prepare science teachers. Ideally, I would like to have more than one science methods course for our PSTs to take – to scaffold ideas across semesters. What is the right number of methods courses? Working within the structure that our program has in place (Table 1), there are opportunities to provide more robust experiences for science methods students – some measures we as a faculty have already taken. For example, we just recently began offering a "STEM" section of the "Technology & Instruction" course that PSTs take in their first semester as the way technology is used is the science or mathematics classroom can be different from the ways technology is used in a history or English classroom – there are overlaps, but there are discipline-specific differences. Perhaps there are other courses in our program that could fit this differentiation? Finally, there is always the opportunity to connect the experiences in PSTs pre-practicum placements more into the discussion of the science methods course. While I do this in meaningful ways as much as possible by having the PSTs reflect on their experiences and situate them among our discussions, the pre-practicum placements are separate from the course. What would it look like if I (or we as a class) were able to visit the science classrooms and observe the PSTs teaching and interacting with students? This is done in during the PSTs practicum semester (semester 4, Table 1), but are there ways to make the earlier pre-practicum experiences more connected to the experiences in the courses? I am interested in the discussion this book will spark.

NOTES

1 MA does not utilize national standardized assessments for K-12 students. Instead they have developed their own standardized assessments, MA Comprehensive Assessment System (MCAS), based on the MA Curriculum Frameworks. For details, see: http://www.doe.mass.edu/mcas/

2 For details on the MA Tests for Educator Licensure, see: http://www.doe.mass.edu/mtel/

3 For details on the MA Educator Evaluation Framework, see: http://www.doe.mass.edu/edeval/

4 A science safety module includes resources available at: htttp://www.nsta.org/safety/

5 To access the photosynthesis simulation, see: https://www.biologycorner.com//flash/waterweed.html

6 The simulation requires Adobe shockwave player plug-in, so having computers on hand already updated to run to the simulation is advisable, as a considerable amount of class time can be lost if PSTs try need to update plug-ins on their personal laptops.

7 The Minds of Own video series was produced by the Harvard-Smithsonian Center for Astrophysics (1997) and are available at: http://www.learner.org/resources/series26.html?pop=yes&pid=77. The except that I show from the video "Lessons from Thin Air" is from minute 2:50–6:25.

8 Contact me for a copy of the lesson planning template that I developed for use in the science methods course which explicitly shows how each of these aspects fit together as a guide for PSTs.

9 Critical friends feedback questions include: (1) Describe what you learned from this presentation. (2) Describe elements of the presentation that worked well to convey the main points. (3) Describe suggestions for improvements, modifications, etc. (4) Outline questions that you have for the presenter based on this presentation.

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4. DEVELOPING SCIENCE EDUCATION RESEARCH LITERACY AMONG SECONDARY IN-SERVICE TEACHERS

An Approach at Bar-Ilan University in Israel

INTRODUCTION

Teachers' understanding of science and science teaching influences their actions in the classroom, which eventually influences students' conceptual understanding of science (Anderson, 2015; Schroeder, Scott, Tolson, Huang, & Lee, 2007; Sadler, Sonnert, Coyle, Cook-Smith, & Miller, 2013) and students' attitudes toward science (Christidou, 2011; Osborne, Simon, & Collins, 2003). It is important to help teachers translate such understandings into classroom practices and develop a teaching philosophy that informs their choice of classroom pedagogy and activities (Barak, 2016; Houseal, Abd-El-Khalick, & Destefano, 2014; Lederman, 1999). One of the dominant strategies to improve the teaching of science and help teachers to examine and be reflective of their practice is to engage them in research in science and science education (Capobianco & Feldman, 2010; Kemmis & McTaggart, 1988; Korthagen, Loughran, & Russell, 2006; Windschitl, 2003). This approach reflects the notion that knowledge about teaching is something created among practitioners and not a subject that needs to be transmitted. Following this approach, teachers can begin to construct their own knowledge about teaching through their experience and reflection (Korthagen et al., 2006; Zohar, 2004). Developing teachers as researchers is a recommended approach in teacher education programs that can enhance the implementation of reformed teaching practices and facilitate teachers' understanding of the purpose of teaching science (Roth, 2007; van Zee, 1998).

The Master of Science Teaching (MST) program at Bar-Ilan University in Israel advocates that the purpose of modern science education is to develop K-12 students to become critical, scientifically literate citizens. The program aims to develop in-service teachers as role models for scientific and mathematical literate citizenry through different aspects of our programs and, specifically, through engaging them in research.

A. J. Sickel & S. B. Witzig (Eds.), Designing and Teaching the Secondary Science Methods Course, 53–70.

The MST Program and National Context

The MST program addresses the priorities of the Israeli Ministry of Education, which, for the last several years has promoted the *meaningful learning process reform*. In general, the reform repurposes the role of students and their teachers. The reform emphasizes a student-centred approach in which students discover, process, and create new knowledge thorough a variety of knowledge resources, including peer learning and online learning. It encourages active learning, in which the students navigate their choices, interest, and personal learning style. The teacher, as envisioned in the reform, guides the students to find knowledge resources, guides the learning process, uses different teaching approaches that encourage diversity in knowledge outcomes, and legitimizes different learning outcomes.

As a policy, the Ministry of Education in our country encourages secondary science and math teachers to study for a Master's degree. Thus, studying in Master of Arts programs is currently becoming part of the teacher professional development process toward their proficiency as science and math secondary school teachers. The program enables in-service teachers either to choose a thesis track or a non-thesis track. In the thesis track, students are required to take 18 two-year credits and in the non-thesis track 22 two-year credits. Each credit is equal to one academic hour (50 minutes) each week, for two semesters, and each semester lasts for 13 weeks. In the thesis tracks, students take four credits in research methods, four credits in science (e.g. Biology, Chemistry, Physics, Environmental sciences), and ten credits in science education. In addition, they write their research thesis. In the non-thesis track, students take an extra four credits in science education in lieu of a thesis, where two credits are their final project course that we discuss later.

The next points summarize the program rational and goals for professionally developing our teachers:

- Deepening teachers' science content knowledge
- Deepening and broadening teachers' research activities in science education in formal and informal educational systems
- Applying academic research findings in the field of science education to classroom practice and the educational system
- Constructing teachers' knowledge of the principles of reformed curricula and evaluation research in K-12 science education
- Developing science teachers as leaders in their field

The teachers in the MST program are K-12 in-service science teachers, and most of them teach at middle and high schools. To enroll in the MST program, they need to have a teaching certificate and a Bachelor's degree in science education or a Bachelor of Science degree. The science subjects are tailored for each teacher in accordance to their teaching area, mainly: biology, chemistry, physics and math. In our science teaching domain/mainstay courses, we have teachers from all science disciplines, which enhances the conversations with diverse ideas and infuses inter-disciplinary perspectives. The program's curriculum intends to reinforce the connection between science, science education and research.

The science education courses emphasize two main pillars and are divided into workshops and seminars. Each workshop and each seminar is a two-credit course, meaning each one lasts for two hours each week for two semesters. The first pillar consists of courses designed as workshops. In the workshops, teachers construct their knowledge of advanced research-based science teaching and learning approaches, gain exposure to changes and innovations in science and math education, learn about leading educational research, and discuss the implementation of advanced research-based teaching, learning and assessment methods. These include such topics as inquiry-based teaching and learning, developing higher order thinking skills, conceptual change, model-based teaching, metacognition, argumentation, context-based teaching, communication and learning through individual and social constructivism. The second pillar consists of the seminars. The overarching goal of the seminars is to engage the in-service teachers in educational research in the field of science education. During the seminars, they develop the ability to read science education articles, critique science education research, think of further research questions that could be asked, conduct a literature review, and develop skills for conducting research in science education. This manifests our agenda to prepare teachers for the 21st century challenges at schools and within society and emphasizes the importance of applied research.

Figures 1a-c presents the courses during the two years of studying in the MST program. The program is set in such a way that each course is supported by knowledge and skills acquired and practiced in other courses. Moreover, the main thread, which is science education (represented as the larger gear than the other two in Figure 1a), is the thread in which students take most of the courses. The science education courses are supported with science content and research methods courses. These courses support teachers in completing their research thesis/final project by the end of the two years of learning in the MST program (Figure 1a).

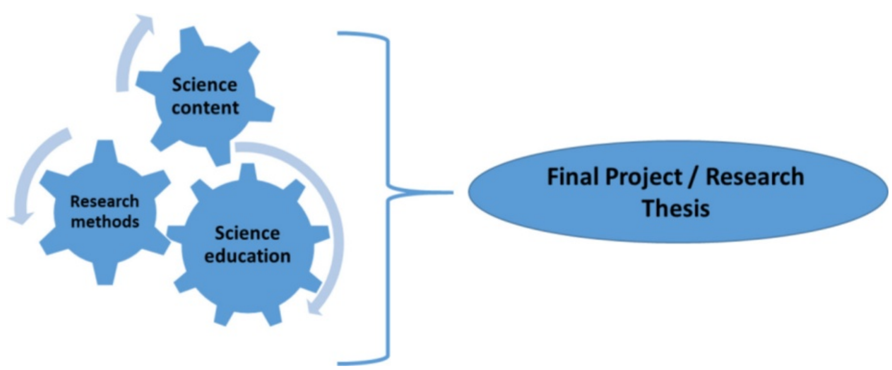

Figure 1a. Three threads of academic courses

At the workshops, teachers discuss and construct their knowledge regarding issues, concepts and educational theories related to the field of science education. For example, in the workshop *Teaching by Structured and Dynamic Inquiry*, teachers build an understanding of inquiry-based teaching and learning processes (Sadeh & Zion, 2009; Zion & Mendelovici, 2012), develop knowledge of the importance of metacognition and self-regulation in inquiry-based learning (Zion, Michalsky, & Mevarech, 2005), and become familiarized with the concept of nature of science and relevant scientific research literature on inquiry-based learning and teaching. Finally, teachers design and experience an authentic dynamic scientific inquiry, and have the opportunity to get first hand familiarization with all stages of scientific inquiry.

Knowledge, understanding and skills acquired and practiced at one seminar are used in the following one. For example, in the first seminar (see Figure 1c for Seminar I) *From Research to Implementation – Innovations in Science and Mathematics Education,* teachers learn the skills of finding, retrieving, organizing and presenting information from the research literature in science education. They are exposed to different electronic databases that are specific to science education, develop the skills of searching for research in their area of interest, and funnel their learning to their area of interest within science education in which they want to broaden their knowledge. Finally, they learn how a scientific article is built and how to present, reflect upon, and critique it. Those skills support their professional development and improve their capabilities as learners and as teachers (Spektor-Levy, Eylon, & Scherz, 2008). These acquired skills are embedded in research activities at the successive seminars, in which they need to plan and execute research skills as shown in Seminar II and Seminar III (Figure 1c).

During seminar I, II, and III teachers are engaged in educational research-based projects and eventually the knowledge and skills obtained during the two years of studying help teachers to conduct their final project (in a non-thesis track) or Master's Thesis (in a thesis track). The final project replaces the individual Master's Thesis research and is suitable for students that choose not to take the thesis track. Teachers who decide to choose a thesis track need to find an advisor and establish an educational research project together. Teachers who choose the non-thesis track complete a more structured research project in groups of 2–3, in which they develop a learning unit that incorporates innovative science teaching methods, conduct an accompanying action research project regarding the learning unit they developed, and present the project according to the requirements of a scholarly manuscript.

PLANNING: DISCUSSION OF COURSE DESIGN

In this chapter, we will describe teachers' learning and highlight the seminar, *Scientific and Mathematical Literacy,* in which teachers conduct their mini-research. In order to do so we will also need to briefly describe the workshop, *Scientific Education – Values and Challenges*, since in this workshop teachers construct knowledge that helps them conduct the mini-research in the seminar.

Workshop: Scientific Education – Values and Challenges

In the workshop, *Scientific Education – Values and Challenges,* teachers develop an understanding of concepts and ideas from the field of learning and teaching science. They develop and discuss an appreciation for the importance of science education in school and in people's daily lives. Ways of achieving meaningful science learning

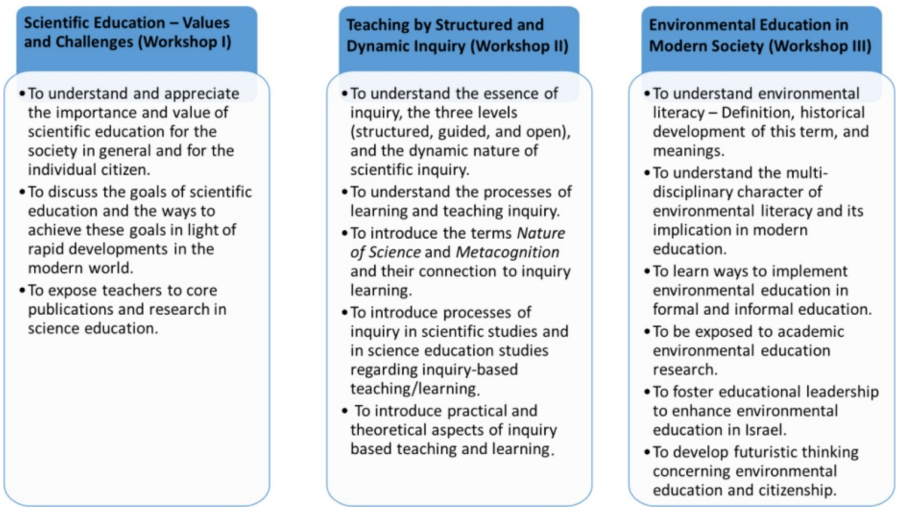

Figure 1b. Instructional goals of the workshops

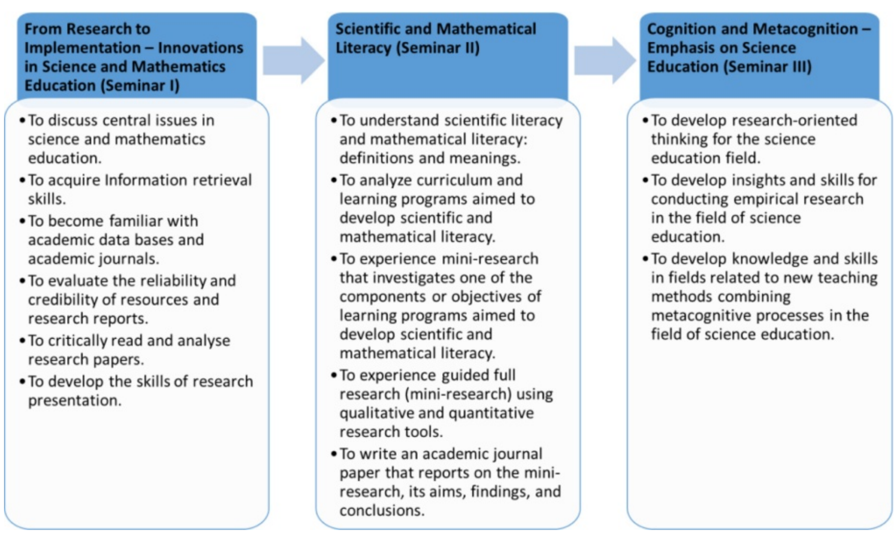

Figure 1c. Instructional goals of the seminars

through professional research literature in science education is emphasized. The workshop includes teachers' presentations of educational theories and theoreticians (e.g. Dewey, Vygotsky, Piaget, Bloom, Ausubel, Bruner, Kolb and others), historical review of science education development in the modern world, and standards-based science education. Furthermore, current issues and leading science education research topics are studied. These include: alternative conceptions and the conceptual change theory, meaningful learning and how to achieve it, teaching for higher order thinking and learning skills, inquiry-based and project-based learning, modeling and visualization skills including analogies, model-based learning and multiple representations in science and math education, gender issues in science and mathematics education, integrating technology and technology-based learning and teaching, learning science in informal environments, and other topics that are at the forefront of science education research.

Seminar: Scientific and Mathematical Literacy

In this section, we describe the design of the seminar, Scientific and Mathematical Literacy, and further discuss the mini-research project as the final assessment.

An Overview of Approach and Topics

We adopted the embedded formative assessment approach that enhances students' higher order thinking skills (Barak & Dori, 2009) and aligns teaching, learning and assessment methods through formal and informal formative assessment strategies (Birenbaum, 2003; Black & Wiliam, 1998; Hickey, Taasoobshirazi, & Cross, 2012; Wiliam, Lee, Harrison, & Black, 2004). This approach contributes to the development of critical thinking, decision-making, and problem solving, and if the goal of our educational system is to develop these skills among our K-12 students, teachers need to experience this approach in order to develop these skills as well.

The aim of the *Scientific and Mathematical Literacy* seminar, as well as the agenda of the MST program, is that teachers will improve during the learning process and maximize their learning potential both as a community and as individuals. During the seminar teachers, learn about topics such as:

- Life sciences, exact sciences and social sciences – what is in common, and what are the differences?
- What is technology?
- Nature of science and philosophy of science
- Social sciences, sociology, and anthropology
- Science education as a defined discipline
- Scientific literacy and mathematic literacy– what is it all about?
- Scientific research, research procedures, and the components of a full research process

- Retrieving academic research papers from professional and popular databases
- Writing a literature review
- Analysis of curriculum and learning programs aimed to develop scientific and mathematical literacy
- Developing a mini-research project

Mini-research assessment. Equipped with knowledge and skills regarding science education as a research discipline, teachers plan their science education mini-research project as a final assessment. The mini-research project applies aspects of practical-cooperative action research (Elliott, 1997). The collection and analysis of data is performed cooperatively among groups of two or three teachers. The teachers participate in the process of planning the research, determining the research goals, preparing the research, and conducting the research. However, since it is a min-research project, it is conducted over the course of two semesters, and they do not engage in iteration cycles.

Conducting the mini-research entails the examination of teaching methods in their classroom and assessing students' outcomes and success in light of pedagogical interventions. Based on their knowledge constructed in other courses, teachers choose a topic and design their research as a group. Through thinking, discussion and reading of relevant literature, teachers develop their knowledge regarding aspects of curriculum development, teaching, learning and assessment in science education, and different approaches to develop meaningful understanding and scientific literacy. Thus, they are developing their ability to funnel their interest into a science education issue they want to investigate. Through the seminar and their mini-research project, they develop their knowledge about the following topics:

- Life sciences, exact sciences and social sciences – what is in common, and what are the differences?
- What is scientific literacy and mathematical literacy?
- Learning programs – rationale, goals, and learning outcomes
- How curriculum and learning programs are translated into teaching and learning materials
- Research tools in social sciences and education
- Conducting guided research (mini-research) using qualitative and quantitative research tools and reporting findings in an academic paper

Examples of topics teachers chose to investigate are:

- The influence of environmental education programs on students' attitudes toward their environment and their ecological sense of place
- The contribution of explicit meta-strategic knowledge on the development of higher order thinking among low achievers
- The influence of e-learning on students' motivation, self-efficacy and understanding of the circulatory system

The process of getting started with the mini-research project includes scaffolds during the first weeks of the first semester. These scaffolds include:

- Reading a full Master's thesis from the library – each teacher chooses a research thesis and reads it. Next, teachers get into groups of three and work together to compare and contrast aspects of the three different Master's theses. To scaffold the discussion, teachers are asked to examine its length and the structure of the chapters, describe briefly the research, explain why they chose this specific Master's thesis work, and describe two positive points of interest and two points of criticism. In the final step, each group reports to the rest of the class.
- Getting organized: In class, teachers form their research teams, and start to discuss the aims of their mini-research with help from their peers and from the instructor

There are multiple opportunities for scaffolding throughout the development of the mini-research project. This process of assessment follows the embedded formative assessment approach. The instructor's goal is to improve teachers' knowledge and skills through the process of learning. The requirements and assessment components are as follows:

- Participation in class discussions and in on-line forums, and demonstrating active learning
- Submission of seven intermediate tasks that contribute to and are relevant to the mini-research: critical reading and presentation of a thesis chosen from the library, research proposal, literature review, developing questionnaires, planning an interview and an observation, collecting and processing data, and writing an academic paper
- Submission of a final paper: The paper includes the title, name of researchers and affiliation, 200-word abstract, introduction, literature review, research aims, research questions, methodology, findings, conclusions and discussion, and appendices

Teachers submit drafts of the assignment through the Moodle platform. The instructor and the teachers read other groups' drafts and help them improve their assignments before the final submission. The seminar has a website provided through the university Moodle platform on which teachers can engage in discussions in an open forum and critique each other's work. The instructor gives the teachers an intermediate assessment and they have the opportunity to improve the drafts of each assignment. The support of the instructor is provided throughout the entire year in class, through e-mails, and personal meetings with the teachers. This ongoing support scaffolds the teachers' ability to regulate and improve their learning.

The Rational for the Sequence of the Workshop and the Seminar

The workshop, *Scientific Education – Values and Challenges,* and the sequential seminar, *Scientific and Mathematical Literacy,* are taught for two semesters and each class lasts for two academic hours a week. The maximum number of teachers in the classes is twenty, and most of the assignments and activities are designed for group work. The rational for this sequence is that teachers will build their knowledge about science education as a research discipline, which evolves through time, and will conceptually understand its roots, development and significance. Through this process, teachers are building their knowledge about scientific and mathematical literacy. They learn how to design a pedagogical intervention to enhance scientific and mathematical literacy, and experience all aspects of investigating a science education topic, including writing a literature review and research questions, conducting the intervention, collecting data through questionnaires, observations and interviews, analysing the data and finally reporting their mini-research in an academic paper. The mini-research is conducted in groups, which enables them to collaborate with and learn from each other, and create their own community of practice to improve their views of science education teaching practice (Akerson, Cullen, & Hanson, 2009).

Literature Framework for Courses Rational

Science education reforms will be difficult to implement and may be unreachable without teachers developing understandings of the reform vision (Abell, 2007; Avargil, Herscovitz, & Dori, 2012). Since teachers usually teach the way they have been taught (Muijs & Reynolds, 2002; Spektor-Levy, Sonnenschein, & Zion, 2005; Windschitl, 2004) it is important to engage them in different teaching methods, investigate new interventions, and report on their results. Teachers as researchers is an essential framework for science teacher preparation and professional development programs (Eilks & Markic, 2011; Wilson, 2013). Teachers who investigate educational topics in the classroom are more reflective on their own teaching and start to become aware of their conceptions about science education and their practices. Furthermore, they develop their conceptions about students' ideas and thinking (Putnam & Borko, 2000). We encourage teachers in the classroom to "reflect upon their beliefs and understandings about learning, teaching, students, and the subject matter" (Davis, 2003 p. 27). Efforts to help teachers understand and implement reformed ways of teaching and reform innovation should include reflective examination of their own practice together with their peers and discuss these issues with one another (Windschitl, 2002). As stated by Borko, Jacobs, and Koellner (2010): "*If we want schools to offer more powerful learning opportunities for students, we must offer more powerful learning opportunities for teachers – opportunities that are grounded in a conception of learning to teach as a life-long endeavor"* (p. 548).

Aligning Course outcomes with Government Priorities and Policy Initiatives

The Ministry of Education policy agenda regarding teachers' professional development is guided by the slogan "The teacher as a learner – from learning experience to teaching experience”. The division of teacher professional development under the Ministry of Education developed a national comprehensive program of professional development for meaningful learning. The program goals for teachers (as stated at the ministry website[1]) are:

- Learning and clarifying concepts and notions of meaningful learning
- Exploring teaching practices, learning, and assessment that promote meaningful learning and implementing these in the teacher’s classroom
- Developing ways to promote the knowledge about learning and learners in order to promote students learning
- Constructing professional knowledge about assessment that promotes learning
- Developing life-long learners for teachers’ professional development and self-efficacy

In the document “Pathways for Meaningful Teaching – a Spread of Practical Models for Meaningful Teaching,” (in Hebrew) guidelines and examples are given for teachers. The guidelines emphasize first, that teachers’ learning and teachers’ practice are not separate entities; teachers need to learn in the context of their teaching, and they need to experience their teaching methods, as they themselves were the students. Secondly, teachers’ learning process belongs to the teachers and is aimed for the teachers, thus, teachers need to be active in investigating their practice. Thirdly, teachers’ learning should be seen as a developmental process. Beyond these guidelines, the document specifies different teaching methods teachers should learn about and incorporate in their teaching in order to promote meaningful learning in their classroom.

The workshop and the seminar in our program are aligned with the above reform. Teachers in our program are engaged with topics of meaningful learning through presentations, discussion, reading, on-line forums, and eventually engaged in a mini research project investigating a teaching method and its implementation in the classroom. During the process, each group presents each stage of the mini research in front of their peers that practice critical thinking. Thus, their understanding of current science education literature, research questions, methods, and research tools is developed. Regarding assessment, teachers in the MST program are being assessed through embedded formative assessment in which every step of their mini-research process is being assessed through peer review and by the instructor.

CLASSROOM PRACTICE: VIGNETTE OF A SIGNATURE LESSON

Teachers conducting the mini-research project are equipped with knowledge they developed in the workshop, *Scientific Education – Values and Challenges*, which in turn helps them decide on a research topic. Therefore, we will describe a signature lesson from the workshop. One of the workshop topics is the use of multiple representations, including analogies, models, visual representations, simulations, and animations. This topic is directly related to conceptual understanding of science, nature of science and the understanding of the nature of modelling and visualization in science. Designing learning environments, which foster meaningful learning by integrating multiple representations, is a goal for both educators and curriculum developers in the last decade (Ainsworth, 2006; Kozma, 2003; Tang & Moje, 2010; Waldrip, Prain, & Carolan, 2010). Teachers, as well as students, do not always share the understanding that scientists hold regarding the use of models in science, and do not use models to construct and critique knowledge. The construction of this lesson is supported by contemporary perspectives on model-based teaching and learning (see Clement & Rea-Ramirez, 2008) and the notion that modelling is a scientific practice that includes the cycle of testing and revising scientific models (NRC, 2012). The design of the lesson is based, in part, on an NSTA webinar[2] on developing and using models that was presented by Christina Schwarz and Cynthia Passmore. Typically, this lesson takes between 2–3 class sessions, 90 minutes each. The lesson starts with a discussion of how the in-service teachers use models in their classroom. The instructor suggests a few insights in order to start the discussion. The following question evokes the discussion: What is the most common way that you use models and modelling in your classrooms? The following possibilities are gradually introduced during the ongoing discussion: (a) to show students what some aspect of a physical phenomenon looks like, (b) to help students remember or reinforce ideas presented in class, (c) to assess students' ideas, and (d) to help students develop or reason with ideas. After the discussion, teachers are asked to participate in an in-class on-line forum and write answers to the following questions:

- How would you explain what is a scientific model to a person who is not familiar with models?
- Describe a model you use in your science class and the goal of using it, what are the advantages and disadvantages of using this model?
- What aspects regarding models are important for your students to learn in your class?

After each teacher participates, we share the answers and discuss them. Thus, teachers can confront their own knowledge and beliefs about scientific models and about their peers' knowledge and beliefs. In order to develop the discussion and give it some theoretical foundation, teachers are then asked to read pages 56–59 in the "Framework for K-12 Science Education" document developed by the National Research Council (NRC, 2012), which addresses the concepts of developing and using models. In order to further delve into the concept of modeling, each teacher is asked to individually draw a model of two containers of water; one with an open cover and one with a closed cover. Teachers are asked to explain their models by describing what would happen during the next three days. Water cycle and phase changes are dominant concepts in each science discipline and represent a disciplinary crosscutting concept as well. The goal of this activity is to show teachers how this concept can be understood through model-based learning. The result of modeling the two containers demonstrates for teachers that each person draws the model in a different way and emphasizes different aspects of the phenomena (see examples in Schwarz et al., 2009). By engaging in this activity, teachers are exposed to the idea that each person has a different mental model of the phenomenon, emphasizes different aspects of the phenomenon, and can improve the model s/he drew with further study.

In the closing whole class-discussion, teachers discuss how to work with their own students on conceptual or expressed models in the classroom (Coll, France, & Taylor, 2005). They discuss how to reveal students' mental or internal models and advance these models to come closer to current understandings of how the world works by productively engage students in modeling. Finally, teachers go back to the in-class online forum and reflect again on their thinking about models. Some insights teachers mention are their perspectives that models are not necessarily 3D physical models (for example, models can be drawings or graphs) and are not final products that one needs to formally present but rather a means to develop an understanding. Teachers also had insights about their own teaching with models. Some examples are that teaching with models requires a discussion of what the model does *not* represent, a misuse of models can create misconceptions, and there is a need to use different modes of representations for the same concept in order to prevent students' misconceptions.

We have learned from doing the activity that in-service science teachers still need to develop their understanding and perceptions of what it means to teach with models and how to develop students understanding through modelling. The notion that a model is something that progresses through learning and can help students develop their thinking was not dominant in teachers' initial perspectives of models (also documented at Danusso, Testa, & Vicentini, 2010; Oh & Oh, 2011; Schwarz et al., 2009).

ASSESSMENT: VIGNETTE OF A SIGNATURE ASSESSMENT

One of the requirements of the workshop and the seminar is participating in an online forum. The forum gives teachers an opportunity to discuss deeply a science education issue. These forums are conducted four times a year. Instead of attending class face-to-face, the teachers and instructor have an opportunity to discuss a particular issue for an entire week through an asynchronous forum, based on the journal club format presented by Barak and Dori (2009). In each forum, the teachers are involved with critically evaluating a science education article that presents a topic related to teaching or learning science. The teachers answer the leading questions posed by the instructor and then continue and elaborate the discussion. The evaluation is assessed according to a rubric, which is given to the teachers before the forum is opened. Thus, the teachers know what is expected from them and can regulate their participation accordingly while also maximizing their learning. We consider this approach as assessment for learning rather than an assessment of learning (Abell & Siegel, 2011; Crisp, 2012; Dori & Avargil, 2014; Wiliam et al., 2004).

One of the online forums was related to the topic, 'elements of teachers' pedagogical knowledge regarding instruction of higher order thinking' (Zohar, 2004). The study investigated elements of pedagogical knowledge when students' higher order thinking was an explicit and focused instructional goal. The questions teachers had to answer were:

- Describe the conclusions of the research. Are the conclusions aligned to the results? What are other conclusions you can think of?
- Why is it important to conduct the research presented in this article? Can you answer the research questions raised in the article by considering your teaching in your class?

The goal of the forum was two-folded, first to expose them to the concept and theory of pedagogical content knowledge for teaching higher order thinking skills (Avargil et al., 2012; Gallagher, Hipkins, & Zohar, 2012; Zohar & Dori, 2003) and secondly to contribute to the development of teachers' critical thinking (Barak, Ben-Chaim, & Zoller, 2007; Dwyer, Hogan, & Stewart, 2014; Mulnix, 2012). We also intend that the learning will be active and that teachers can learn from one another. Teachers' assessment was based on the following criteria: (a) answering the instructor's questions in a clear and comprehensive response that refers to the content of the article, (b) participating in the online discussion, (e) responding to classmates' ideas or opinions (f) referencing other articles in their answers or in responding to their classmates, and (g) reflecting on their own thoughts and basing ideas on their own experience in science teaching (based on Barak & Dori, 2009).

After a week of an online discussion, the class convenes to discuss and reflect on the process. Most teachers were very pleased with the way they constructed their knowledge, and were specifically satisfied that they could learn from one another and from examples each teacher brought to the forum. Positive reactions also addressed the broad theoretical knowledge they gained through reading the main article and being exposed to other articles each teacher brought and presented in their discussion on the on-line forum.

We learned that in-service teachers become aware of the approach that transmitting knowledge is not an effective way for promoting meaningful understanding of science. However, teachers said that they do not always have the time or knowledge for teaching for higher order thinking skills; furthermore, there are sometimes obstacles in their workplace environment – for example other teachers and school principals who do not advocate for reform-minded instruction. Most teachers said that they do promote meaningful understanding in their classroom by using different teaching methods. They mentioned different methods like connecting science to everyday life, using associations, and using science theatre; however, they claimed that sometimes students ask them just to summarize the content on the board. Teachers claimed that they are open to reforms and change but expressed that sometimes it does not fit all students. All the teachers agreed that educators need to learn constantly and develop the knowledge needed for teaching science, and this is one of the reasons they decided to learn in the MST program.

CONCLUSION: STRENGTHS AND AREAS FOR IMPROVEMENT

The workshop and the seminar described in this chapter are aimed for teachers' professional development in several aspects. We want teachers to think and reflect on what it means to be a reform-minded science teacher (Luehmann, 2007), how teaching science should be conducted, and how learning science occurs (Zohar, 2004). Some strengths include our broad theoretical guidance that leads the development of the program, the content of the workshops and seminars, the collaboration between the teachers, and the creation of an active learning community. Teachers who graduate from the program reflect positively on their experience and specifically on aspects of their professional development.

We learned that teachers who participate in the *Scientific and Mathematical Literacy* seminar in their first year of learning in the MST program are able to use their knowledge in seminars in their second year. From the aspect of teachers as researchers, they are able to ask research questions, understand what a theoretical innovation in science education is, and are able to select and create research tools that are aligned with research questions. This ability contributes to their scientific literacy in many aspects, as one of the teachers wrote in the reflection:

> During my studies I was exposed to numerous studies in the field of science education; I developed my ability to read and critique scientific articles. I learned how to collaborate with my peers and learned how to work within a group. The most important insight for me is that I think research in science education is very relevant to my teaching and that I can conduct research in my class.

From the pedagogical aspect, we learned that the seminar leads a process of conceptual change regarding teaching (Russell & Martin, 2007; Sherin, 2002) and teachers start to see the strong connection between educational research and classroom teaching. They understand that in order to examine their teaching and develop professionally, they need knowledge and skills in research in science education. Although they are in-service teachers, reforms may cause even experienced teachers to revert to a survival stage as if they were beginners (Huberman, 1993). We learned that the teachers sometimes feel like beginners when they participate in discussions about different instructional methods, assessment, different aspects of nature of science and teaching science, and when conducting research. All of the in-service teachers indicate that they develop knowledge and skills, both as individuals and as teachers. Still, although teachers appreciate the diversity of perspectives, some indicated that there is a need for some separation between the disciplines (chemistry, biology, mathematics, physics, etc.) and concentrating on specific features of teaching and learning the specific science discipline. Another improvement that might contribute to the program and the design of the workshop and seminars would be the inclusion of teacher observations and video-recording their practice when they implement innovative ways of teaching science. Thus, discussions of teaching science could then be situated on authentic artifacts, such as video clips from teachers' lessons, and be more closely related to classroom practice (Borko et al., 2010).

NOTES

[1] http://cms.education.gov.il/NR/rdonlyres/420EDACE-8E24-40E2-92C9-33700EFF3DD6/194737/MeaningfulLearning23092014.pdf (in Hebrew).

[2] http://learningcenter.nsta.org/products/symposia_seminars/ngss/files/preparingforngss--developingandusingmodels_9-25-2012.pdf

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5. STEAM METHODS

A Case from Egypt

INTRODUCTION

This chapter presents the case of science education in Egypt within the context of Science, Technology, Engineering and Mathematics (STEM) and Science, Technology, Engineering, Arts and Mathematics (STEAM) education. Although Egypt is one of the Arab countries that shares with its neighbours social and cultural values, language and historical incidents, what is currently taking place in terms of the emphasis on STEM/STEAM education presents a unique model that is not found in other Arab state countries in Africa or in the Gulf. To present the reader a wider perspective of why and how this is happening, a brief background on the Arab region and Egypt's general positioning of science education, STEM/STEAM education and teacher preparation is put into perspective.

In the Arab region, including Egypt, there is major concern on the quality of education (United Nations Development Programme, 2002). Unemployment rates are high, reaching to about 30% in most Arab countries and illustrating a mismatch between the outputs of the educational system and the needs of the job market. It is even documented that 40% of employers are unsatisfied with the knowledge and skills of their employees and therefore offer training programmes to compensate for missing knowledge and skills. The 2008 World Bank report argues that education in the Arab countries is not preparing students with the necessary skills needed for the 21st century. It also states that the "impact of the considerable investment in education has been less than expected in terms of economic growth, the promotion of equality and reduction of poverty" (World Bank cited in Dagher & BouJaoude, 2011, p. 75). An indicator of the limited quality is the Trends in International Mathematics and Science Study (TIMSS) that illustrates many Arab countries scoring relatively low. All participating Arab countries in 2003 and 2007 scored below the international average except for Jordanian grade eight students who ranked around the international average (Mullis, Martin, & Foy, 2008).

In an attempt to try to outline the main challenges of science education in the Arab countries, Dagher and BouJaoude (2011) referred to the out-dated curricula, traditional methods, emphasis on factual knowledge and theory at the expense of hands-on practical activities, limited access to appropriate technologies and insufficient budgets. Expenditure on education varies as whether it represents one

A. J. Sickel & S. B. Witzig (Eds.), Designing and Teaching the Secondary Science Methods Course, 71–87.

of the oil countries. In Egypt, expenditure on education is minute (4% of the total income) compared to neighbouring countries. The 2014 Egyptian constitution suggested increasing it to 6%, yet this will not take place until after three years and will likely have little impact on the system in short and long terms. To resolve the current status of science education in the Arab countries, many efforts have taken place to introduce new reform initiatives. The reason behind such initiatives is a need for learners in K-12 classrooms to do more science and be actively engaged in the scientific process with an emphasis on quality teaching and learning. Yet, there is evidence of a decline in the number of learners with an interest in entering career pathways in the sciences (Rissmann-Joyce & El Nagdi, 2013; Wyss, Heulskamp, & Siebert, 2012), adding pressure to the governments that want to perceive their countries in a better place nationally and internationally and to those who want to take leadership roles technologically and economically. In an earlier study, BouJaoude and Dagher (2009) stated that the problem with science education is manifested in the lack of qualified science teachers. Huffman (2006) claims that reforming science teaching is difficult because of the complex nature of science learning environments. Various studies echoed this view as they noted that both pre-service and in-service teachers find it challenging to implement and shift to inquiry-based and constructivist teaching (i.e. Beck, Czerniak, & Lumpe, 2000).

Recently, the Egyptian government has invested in secondary education reform (grades 10–12) with an aim to better prepare students for today's complex world. One of the major reform efforts happening at the secondary stage is the launch of Science, Technology, Engineering and Mathematics (STEM) schools that strengthen student capabilities in these fields in a search for science-based solutions to daily societal problems in the country (Singer, 2011). With low international rankings in TIMSS tests, a clear decline in the number of students enrolling in the science track at the secondary stage and a gender gap between female and male enrolment at the lower and upper secondary stages, two pilot STEM schools were established as the first schools in Egypt and the Arab region. The STEM Public Secondary Schools were established by the Egyptian Ministry of Education (MoE) with an aim to provide access to quality education for gifted students. This is through presenting students with integrated curriculum via project based learning (PBL), critical thinking and real world applications needed for the job market. STEM Schools in Egypt also plan to serve as incubators for future leaders and innovators. With such vision, leaders will have the potential to advance the forefront of research and development initiatives needed for scientific invention and the generation of more employment opportunities and economic growth. The first STEM school started in 2011 with a generous fund of $25 million from the United States Agency for International Development (USAID) that established an educational consortium for the advancement of STEM in Egypt (ECASE). The school was a boys' segregated boarding school followed by establishing a segregated boarding school for girls in 2012.

With the rise in the number of STEM schools throughout Egypt, more STEM teachers are needed. Seven new schools started in 2015/2016, adding to the two excising ones. Recruitment takes place through the Professional Academy of Teachers' (PAT) website. The qualifications needed for the job, in addition to English proficiency and subject specialization, is to be civic-minded, capable of being a STEM problem solver teacher and ready to be part of the professional development training provided at each school by international STEM experts. Candidates need to pass a number of tests to qualify for the job. This includes an aptitude test, subject matter test and English test. Those applying for leadership posts need to pass an additional leadership test (PAT, 2015). Once teachers are accepted for the posts, collective efforts from the Franklin Institute, Teaching Institute for Excellence in STEM (TIES) and The 21st Partnership for STEM Education (21pSTEM) are formed to develop and conduct training workshops. Training is deemed necessary especially as the STEM schools come with different teaching and assessment practices to those well known in the Egyptian schools. Curricula at the STEM schools are designed around grand challenges in Egypt and assessment is through formative and summative collaborative capstone projects. The unique assessment provided by the STEM schools replaces the well-known *thanniwiyya amma* (General Secondary Certificate, GSC) that is highly based on rote learning. With the governments' priority plan to establish more STEM schools and with the urgent need to attract students, especially females to STEM disciplines, more needs to be done with teacher preparation programmes. The next section discusses one of the programmes that helps prepare teachers for such integrated practice.

PLANNING

The course described in this chapter is situated at a graduate school of education in a private non-profitable university in Egypt. The Graduate School of Education (GSE) aims to promote equity and excellence in education in Egypt and the region. The GSE presents various programmes to those from different backgrounds whom share an interest and passion in education. The school offers two Masters in Art (MA) programmes: International and Comparative Education and Educational Leadership. The other programme offered by GSE, is the Professional Educator Diploma Programme (PED). This programme is for educators, school owners, government supervisors and NGO educators who wish to either improve themselves or their schools. Teachers in this programme could also include those who wish to change careers into education and for those who want to make a difference to education in Egypt. There are four main tracks in PED: Educational Leadership, Teaching Early Years Learners; Teaching Adolescent Learners; and the Professional Educators Diploma in STEAM. The GSE homepage states details of its PED programme as follows:

> Each professional diploma requires six courses that cover both theoretical and practical experiences. The courses may be completed as a fast-track option over three semesters and one summer session. Four semesters are the regular

> option. Diplomas are awarded upon successful completion of all courses. (GSE Homepage, n.d.)

Within the STEAM track, eight courses are offered where six are compulsory and two are elective. Teachers select between ‘How children learn mathematics and science’ and ‘How adolescents learn mathematics and science’, depending on the stage they are currently teaching or are interested in. This counts as their first compulsory course whereas the other compulsory courses are: ‘Alternative assessment for STEAM’; ‘Interdisciplinary pedagogical methods for STEAM’; ‘Integrating the arts into STEAM’ and ‘STEAM practicum’. To complete the number of courses to graduate from the programme, teachers and prospective teachers need to select one of the two elective courses: ‘Engineering design for maths and science learning’ or ‘Technology for STEAM’. Although these are two different courses, those who select the technology course will still be provided with opportunities as to how to integrate engineering and vice versa. The intention to present a track on STEAM education was mainly to fill one of the gaps found in the Egyptian teacher education system, especially with the increase in the number of STEM schools and a better understanding of its philosophy and impact. Teachers are only prepared to teach one subject in its silo with limited opportunities to expand to other disciplines in the sciences or humanities. To help change this perspective and offer teachers with innovative teaching and learning practices to help the country achieve its aim by attracting more into the sciences and meet job market requirements, this track was introduced in the PED programme. Moreover, it is a means to provide teachers and those interested in STEM/STEAM education with opportunities to understand and implement this innovative practice, thus increasing their efficacy and self-confidence (Nadelson, Callahan, Pyke, Hay, Dance, & Pfiester, 2013).

The STEAM track is centred on the interdisciplinary approach for student learning. It should be noted that much of the literature on interdisciplinary learning stresses on STEM education, whereas at GSE there is a deliberate intention to include the ‘Arts’ into the equation. The reason for this is mainly that learners in real-life situations do not seem to identify and associate issues around them within certain disciplines, nor is it likely possible to disregard the human aspects and social dimensions in any given situation. Complementing this view, Tarnoff (2010) and Pomeroy (2012) claim that STEM education is missing a set of creativity components and skills that are summarized under the letter “A” for Arts. This set of skills comes particularly essential to jobs where the ‘flattening or ‘levelling effect’ are taking place in the world’s current workforce, where all countries, companies and individuals in the world have an equal opportunity to compete in the global market (Friedman, 2007).

The need to add the arts represented by the ‘A’ in STEAM education links to brain-based-research. It shows an emphasis on both hemispheres of the brain (right brain hemisphere responsible for creativity and left brain hemisphere responsible for academia and logic) as a whole brain system. Unfortunately, most science education teaching and learning practices in the States (White, 2010) and in the Arab countries focus on the left hemisphere and neglect the right side of the brain. Therefore, various international calls to shift from STEM to STEAM have a sound rationale and support the STEAM model adapted and presented at GSE in Egypt for teachers, school administrators and stakeholders in education.

Building on the reason of why STEAM and not STEM, more detail on the 'Interdisciplinary pedagogical methods for STEAM' course follows. The course is part of the track as it focuses on methodologies for teaching science and mathematics through interdisciplinary projects. The main aim of the course is for teachers to learn the various theories behind interdisciplinary education. There is major focus on constructivism and information processing theories of learning as they stress on conceptual understanding and making connections as well as meaningful learning through chunking and memory. Teachers learn through applying these theories to activities for learning specific content as they explore techniques for integrating subjects together. According to the current status of teaching and learning science in Egyptian schools, as highlighted above, interdisciplinary learning is a radical approach compared to most current teaching practices. Therefore, teachers need to understand the philosophy behind it before enacting such pedagogies in their daily practices. According to Vasquez, Comer and Sneider (2013), STEM education is not a curriculum by itself, but it is an approach for teachers to organise and deliver instruction in a way that helps students apply their knowledge with their peers in meaningful situations. This approach is supported by the recognition that real life problems are not found in separate disciplines (Wang, 2012).

The focus of the course is to shift teaching practices from traditional lecture-based teaching into those that are inquiry, project-based and problem-based as a means to present integrated, meaningful learning experiences that could include two or more of the main disciplines identified in STEAM education. Specifically, it aims to make changes in teachers' practice and increase STEAM content knowledge (CK) and pedagogical content knowledge (PCK). Within such interdisciplinary philosophy, deep conceptual understanding and what is termed as 21st century skills could be developed (Biasutti & El-Deghaidy, 2015). Furthermore, this study is based on the STEAM integration research framework where teachers act as facilitators to expose students to meaningful learning experiences that enrich their deep content understanding in the STEAM disciplines and then establish connections to everyday life experiences. In a description of the key elements that contribute to effective STEM instruction, the National Research Council, NRC (2011) emphasised inclusion of "a coherent set of standards and curriculum, teachers with high capacity, a supportive system of assessment and accountability, adequate instructional time, and equal access to quality STEM learning opportunities" (p. 25). Ultimately, the STEAM integrated framework builds on developing new models of teaching that foster such integrated meaningful learning experiences. Science teachers should be able to offer learning opportunities that provide their students with authentic learning through provoking their understanding of the various concepts in the various STEAM disciplines when working with others and applying their knowledge and skills to solve problems creatively. For this to happen, teachers need guidance and training. There is also evidence that teachers themselves need to be exposed to learning experiences that appreciate positive roles and high levels of hands-on and minds-on engagement (Daugherty, 2009). Teachers' positive roles are those that are based on the principles of constructivism where they are engaged in collaborative activities that require in-depth, active learning opportunities. With the absence of a framework in Egypt similar to that of the Next Generation Science Standards (NGSS) in the US, this course was designed with a social-constructivist framework through the design phase. This led to developing activities where teachers would work in social contexts while exchanging and challenging experiences and ideas. Through constructivism, there is emphasis on how people learn and the complexities surrounding learning were taken into consideration, especially with a view of teachers as learners (El-Deghaidy, Mansour, & Alshamrany, 2014). Throughout the course design, there was also a great appreciation of the role of cognition and learning and how STEAM education favours connected concepts over those which are unconnected. This is crucial when it comes to connecting concepts from different STEAM disciplines and from different stages of their learning, especially since learning is about constructing and reconstructing knowledge (Novak, 2002). Therefore, the course presents rigorous academic concepts that are coupled with real-world lessons. Within such context of implementing problem-based learning, teachers are to apply STEAM disciplines through connections between school, community and work. The educational goal is to enable educators in the development of STEAM literacy and with it, students' ability to innovate and become leaders of tomorrow's industry.

In general, all courses offered under the STEAM track are designed using a slightly modified version of the 'Backward Design' curricula approach (McTighe & Wiggins, 2004). Each course starts with a brief overview. Courses are referred to as 'modules' that consist of a number of 'units' depending on the length and detail required, yet for the sake of this chapter and to avoid confusion, the words *course* and *topics* will be used instead. While designing the module/course, deep thought was given to what teachers need to know, understand, and be able to do. 'Big ideas' and a range of assessment methods to showcase evidence of their understanding and skills were also taken into consideration. Finally, activities were designed to help achieve the desired results. The course explicitly highlights the main learning outcomes using measurable action verbs. This is followed by the course grand challenge. Activities presented throughout the course form the mini-challenges for teachers to work through and experience. Units/topics also have a brief overview, learning outcomes and essential questions. A number of suggested readings are provided to help understand the 'big ideas' covered in each topic.

The learning outcomes for the 'Interdisciplinary pedagogical methods for STEAM' course stress on major ideas that are expected to be achieved by teachers. With these outcomes, the emphasis is on understanding pedagogies such as inquiry-based learning, project based learning and the problem based learning, and how these generally apply to the Sciences, Engineering, Mathematics, and non-science areas. Teachers learn to teach science as related to gender, culture, race/ethnicity, through active engagement and participation, and with an emphasis on student perspective and inclusion. In addition, they demonstrate understanding of teaching in a STEAM classroom by developing a unit integrating STEAM principles.

The main grand challenge that governs this course requires teachers to design a group unit to be presented at the end of the course, showing their understanding of the interdisciplinary approach for STEAM. To reach this grand challenge, teachers are taken through the concept of interdisciplinarity gradually, as they increase the number of integrated disciplines and the nature and depth of such integration. This unit design is considered the main assessment of the course, as it reflects the big ideas and major concepts presented and implemented throughout the 12 weeks. The interdisciplinary unit expected to be designed should consist of at least two lessons/activities. The unit starts with an overview, indicating its main aim and the disciplines involved. The grand challenge is made clear and connections to the other disciplines are stated through reference to discipline standards. Details of the lessons/activities include timeframe, materials, instructional strategies and details of what and how to assess. This includes designing and presenting needed rubrics, questionnaires, and observation sheets to assess school student learning.

In addition to this group challenge, each participant is required to develop an individual lesson plan and demonstrate how to conduct it in class. This is mainly to assess how teachers in this course can develop integrated lesson plans, that include more than one discipline integrated together, and also present a lesson through micro-teaching. Micro-teaching is used to assess teachers' pedagogical and presentation skills through simulating real-time teaching experiences. The main benefit of using micro-teaching is to provide teachers with an opportunity to enact some of the pedagogical skills and also to reflect on such practices (Mergler & Tangen, 2010). This is especially possible as they record their lesson demos and are provided feedback from their peers (Ostrosky, Mouzourou, & Danner, 2013). This in itself is a rich learning experience for those who are starting to transform their practices to enact STEAM integrated practices. A different rubric than that of the designed interdisciplinary unit is used to assess this practice.

As for the mini-challenges, these occur through bi-weekly 'reflective logs' which form a systematic record of teachers' learning. Reflective writing is a core feature of the assignments. It is meant to enhance teachers' thinking skills and enable them to develop into reflective practitioners. Reflection is perceived in the context of this course and GSE in general as a higher order thinking skill that requires teachers to self-assess their understanding of the core concepts presented so far in the course (through class activities and course material), and relate this to personal beliefs that govern their pedagogical practices in class. Such a combination is needed to help teachers rethink their current pedagogical practices and help construct and reconstruct their beliefs and practices (Hatton & Smith, 1995; Shandomo, 2010).

Moreover, teachers carry out hands-on activities where they are actively and personally involved through the reflective activities and various levels of application if applicable to the unit. For example, topic one in “What is STEAM? The nature of STEAM education” has two learning outcomes: (1) Define STEAM education; and (2) Demonstrate understanding of the components of the STEAM approach. There are 3 essential questions that guide this unit:

- What is STEAM education?
- Why is it needed in the Arab World and in our case in Egypt?
- What are the main components of the STEAM approach?

Another example that I would like to share is that from topic four. The topic outcomes aim for teachers to show in practice their understanding of STEAM interdisciplinary pedagogies through designing and presenting STEAM lessons. The essential question that guides this topic is: How can we show our understanding of the interdisciplinary pedagogies in real life practice? Detailed examples are provided in the following section.

CLASSROOM PRACTICE: VIGNETTE OF SIGNATURE LESSONS

The topics of this course are presented throughout a 12-week semester. This includes the number of classes needed to cover the topics in addition to final presentation sessions of their interdisciplinary units. In general, the course is structured around three-hour weekly sessions that include mini lectures, discussions of assigned readings, group work, and individual and group presentations. Teachers need to come to class having read the course material to analyse the ideas presented in the reading material and form their own views and opinions. Interaction and engagement is highly required as the course is built with a participant-centred constructivist philosophy in mind. Therefore, searching for information, adding material and sharing with others is how communities of learners are established. Moreover, discussions during class time is highly related to teachers’ own practices, experiences, views, and social and cultural context. The following discussion illustrates two examples from the interdisciplinary course in the STEAM track. The first example aims to identify teachers’ perspectives of STEM/STEAM education and the applicability of implementing it in the Egyptian context. The second example aims to present examples of unit and lesson plans that investigate possible means of integrating the different disciplines together through inquiry-based learning.

STEM/STEAM in the Egyptian Context

Before identifying teachers’ perspectives in regards to STEAM education, some background information from each participant is collected. This includes years of teaching experience, grade level of which they teach, number of students in class and their gender. Teachers are asked a few questions linked to interdisciplinary practices. One of them is to know whether teachers seem to be receptive and accepting of the idea of integrating disciplines together and what are the main reasons for not integrating disciplines, if that were the case. To help voice their views even more, teachers are to write a reflective paper in response to these two questions. Each reflective journal is graded using a rubric given to the teachers before actually starting any assignment. Teachers come to class to share their views and discuss how interdisciplinary learning could be implemented in the Egyptian context. This helps the teachers unpack other interrelated issues for these two questions. To respond to one of the essential questions in this unit, teachers think out loud regarding the question, 'why is STEM/STEAM needed in the Arab World and in Egypt?' Typical answers that I get to this question are as follows: education needs to be reformed as the current status is not satisfying students, parents or even workforce requirements; the notion of quality education is sometimes added to clarify what and how the current system is not satisfactory and therefore STEM/STEAM could be a requirement for education in Egypt and elsewhere in the Arab region. Identifying the need to add the 'Arts' with a workforce requirement is not usually identified in the response to this open question. Yet what happens next is quite interesting as rich discussions follow that lead to issues related to challenges with science and mathematics education, private tutoring (a problem that is exculpating in the Egyptian system), what should be the nature of a STEM education curricula, and teacher support through teacher training. Discussions help enable teachers to reflect on previous educational reforms in Egypt by examining its successes/failures in addition to career options. Comments added by the instructor are always useful after a discussion such as this to elaborate on what can be done and accomplished in reality and what needs to be taken to policy makers for further elaborations and discussion. Our class discussions end with a focus on practical suggestions for teachers in the classroom, where teachers see the boundaries of their circle of influence with their students and peers from other disciplines, in a hope to form collegial communities of practice.

Nature of STEM/STEAM

The second example in this course is related to the session on understanding the nature of STEM/STEAM education. Teachers are to come to class having gone through the assigned readings. These include an article by Roger Bybee (2010) 'Advance STEM Education: A 2020 Vision', and 'The integration ladder: A tool for curriculum planning' by Harden (2000). The session starts with a discussion that enables teachers to identify the differences and similarities among the five STEAM disciplines. Each discipline is identified in terms of what it aims to do and a short definition usually presented by the disciplines' main standards. This is to help identify the reasons for integrating these disciplines and the richness each brings to the general integrated context of STEAM. The disciplines for which teachers struggle the most are engineering and technology. The former is not a discipline presented in the school context in Egypt or any country in the Arab region. Yet, what is required when mentioning ‘engineering’ is to think like an engineer by using scientific results to solve problems in the physical world. The latter, technology, is mostly known as hardware and software rather than practical applications of scientific knowledge. The sessions then move on to gaining insights from the readings and the various means of integration. To get teachers more acquainted with the idea of integration, class activities stress on brainstorming various means to integrate more than two disciplines together while in small groups. Teachers struggle at this stage of the session as their teacher education programmes, discipline textbooks and school setting are all for silo learning. Thinking out of the traditional box is met with some level of resistance and struggle. After brainstorming and gaining some of their insights, they are provided with examples of integration, usually by YouTube videos that help them perceive the new concept. The selection criterion is basically to find videos that show teachers in action, whether at the planning stage or in the classroom presenting to their students and engaging them through examples of integrated projects. They are given another round of brainstorming, especially as the main challenge is to try to think of integrating disciplines other than science and mathematics only, which seem to be the two most common disciplines when it comes to interdisciplinary learning (Brown & Borrego, 2013). Each group then presents their work followed by an open discussion of other alternative means to integration proposed by the whole class. This could include suggestions for different disciplines, concepts or skills to be integrated. This allows for sharing views and also building a supportive collaborative community of learners, which is needed in STEM/STEAM teacher culture (Zubrowski, 2002) to shift away from the silo culture known in the educational system in Egypt and other Arab countries (El-Deghaidy & Mansour, 2015).

ASSESSMENT: VIGNETTE OF A SIGNATURE ASSESSMENT

Building on class activities throughout the course, teachers are assessed at various stages of the course with different rubrics. Teachers need to understand the variety of assessment tools as they themselves have direct experience with such tools. These tools include designing integrated lesson plans, micro-teaching, reflective journals and group design of an integrated unit.

Teachers are required to use a template to develop a lesson plan outline to show consistency among the lessons. The aim is to implement this integrated lesson plan through microteaching sessions. Throughout the sessions, they are to record the presentations and showcase them by uploading the videos on the common Blackboard platform. The platform is assessable through their university credentials. At this stage of the course, it is acceptable to think of possibilities of integrating two disciplines only from the five disciplines of STEAM. Later in the course, they are to think of integrating all various components of the STEAM disciplines, wherever possible. During the presentations, feedback is given. According to the feedback, teachers are to work on their lesson plans and submit for final grading. As mentioned earlier, each group is to collectively design a unit, yet lesson plans are designed individually as indicated above.

Examples presented by the teachers of integrated units included 'green roofing', 'air pollution', 'designing smart garages' and 'global warming'. The green roofing unit integrated disciplines such as science, technology, engineering, mathematics, arts, language and social studies. The unit started with an overview justifying the need for green roofing. It is mainly an issue tied with Egypt's over population and the increase of buildings to accommodate for this increase. As a result, there is a great decrease in fertile land used in farming with less crop production, resulting in a need to find alternatives. The engineering component is in the design of the roof garden as an open-ended challenge that could vary in its shape, size and other factors while determining needed area, material and cost. This challenge had a rubric to assess school student design in terms of group work, reflection, data recorded, design and cost. The unit was organized according to three lessons. In lesson one, students learned about the distribution of water and land in general and in Egypt specifically. They recognised the climate regions, weather conditions, types of crops and suitable weather for each. Students learned about the history of farming with emphasis on the farming tools and methods used starting from those used by Pharaohs. They learn how the arts were used to document Pharaohs' life styles, stages of farming and festivals of harvesting. Students were directed to collect photos and produce an album about the plant regions and the farming in ancient Egypt. In lesson two, students differentiated between the different types of plant adaptation. They were directed to collect data in regards to the types of plants and what each plant produces. They then calculated the mean of the cost and profit of planting certain types. Students can predict income of the roof garden using probability and collect data accordingly. In lesson three, students use geometry knowledge and skills to determine the volume and area of some containers as applications on the rational numbers. They also calculate the costs for planting the roof and are encouraged to search for how to use technology to reduce the consumption of water in farming. They are to assess their initial prototype designs and then redesign in an iterative process. Topics such as climate change and global warming are discussed amongst the students. The unit ended with students presenting and sharing their collective designs as a group. Each time during the three lessons, students were directed to use the internet and search for images, designs and information needed for their project. They were also required to write journals of their daily problems as a story line. Hands-on, minds-on collaborative shared activities is what makes STEAM education a quality setting for students through engaging them in knowledge and skills necessary for solving interesting real-life situations.

Table 1 illustrates the rubric that was used for this integrated assignment. Throughout the rubric, there are four main aspects that are assessed. The first looks at the focus of the unit on 'big ideas' in the various STEAM disciplines integrated

Table 1. Rubric for developing an interdisciplinary unit using the backward design approach

	Components of Stages	*Needs improvement*	*Developing*	*Exemplary*
To what extent does the unit design focus on the big ideas of targeted content?	Unit Focus with framing questions	The unit does not seem to focus on big ideas in any STEAM content areas and lacks a clear relationship to daily life	The unit focuses on big ideas in most STEAM content areas but the relationship to daily life is not clear	The unit focuses on big ideas in all STEAM content areas and clearly shows the relationship to daily life
	Objectives/ aims	The stated aims/goals/ objectives have no reference (i.e. MOE, NAQAAE, international standards) and are not SMART	The stated aims/goals/ objectives are SMART but have no reference (i.e. MOE, NAQAAE, international standards, etc…)	The stated aims/goals/ objectives are SMART and clearly referenced (i.e. MOE, NAQAAE, National standards, etc…)
	Knowledge and skills	Neither knowledge or skills are identified in one or more STEAM content area	Either knowledge or skills are identified in most STEAM content areas or more	Both knowledge and skills are identified in each STEAM content area, in addition to 21 century skills
To what extent do the assessments provide fair, valid, reliable, and sufficient measures of the desired results?	Opportunities for assessing students through authentic performance tasks	Students are not asked to perform authentic performance tasks at all	Students are asked to exhibit their understanding through one authentic performance tasks	Students are asked to exhibit their understanding through two or more authentic performance tasks
	Availability of assessment tools	There are no criterion-based scoring tools used to evaluate student products and performances? (i.e. rubrics)	There is one criterion-based scoring tool used to evaluate student products and performances? (rubrics)	There are various assessment formats used to provide additional evidence of learning including criterion-based scoring tools to evaluate student products and performances

	Opportunities for self-assessment	There are no opportunities for students to self-assess their learning	There are limited opportunities (one) for students to self-assess their learning	There are various opportunities (more than one) for students to self-assess their learning
To what extent is the unit plan effective and engaging?	Inclusion of WHERETO aspects	The project is mapped including limited aspects of WHERETO	The project is mapped out clearly so that students know where they're going, including some aspects of WHERETO (3-4)	The project is mapped out clearly so that students know where they're going, including all aspects of WHERETO
	Technology Integration	Unit Plan does not take advantage of research, publishing, and communication capabilities	Use of technology is limited to using the computer as a tool, a publishing tool, or a communication device	Use of technology enhances the Unit Plan by using the computer as a research tool, a publishing tool, and a communication device
The overall look of the unit & member collaboration	Organization and Appearance	The overall look of the unit is disorganized and unclear, stages are not clear, there is no introduction to the unit or a cover page, and the titles as specified in the templates are not used	The overall look of the unit is organized, stages are clear, but there is no introduction, no cover page, titles as specified in the templates are used	The overall look of the unit is professional, there is an introduction, a cover page that reflects the topic, stages are clear, titles as specified in the templates are used
		The UbD unit shows that members have not been collaborating throughout the stages of the project where each member representing a discipline has not shared in the design	The UbD unit shows that members have collaboratively participated throughout the most stages of the project where each member representing a discipline has shared in most stages of the design	The UbD unit shows that members have collaboratively participated throughout the life time (three stages) of the project as each member representing a discipline has shared in all stages of the design

in the unit. This aspect holds teachers accountable for linking big ideas to real life situations to ensure relevance. It also ensures that there are references to standards identified by the Ministry of Education (MOE), or the National Authority for and Quality Assurance and Accreditation of Education (NAQAAE), and that the objectives are framed as specific, measurable, attainable, realistic and time bound (SMART). The second aspect in the rubric assesses what teachers have included in the unit that are considered as opportunities for their school students' authentic performance. Since STEAM integrated education allows for students' practice of higher order thinking skills, assessments should mirror such practices. Adding a variety of assessment tools, ranging from peer assessment to self-assessment, and other means of monitoring and evaluating learning is therefore required. To measure the unit's effectiveness, aspects related to McTighe and Wiggins's (2004) reference to the 'WHERETO' acronym is used. The acronym summarises what should be included in the designed activities. The 'W' presents answers to the following questions: Where are we going? Why? What is expected? 'H' refers to, how will we hook the students? 'E' refers to, how will we equip students for expected performance? 'R' refers to, how will we rethink or revise? The 2nd 'E' refers to how will students self-evaluate and reflect on their learning? 'T' refers to, how will we tailor learning to varied needs, interests and learning styles? And 'O' refers to, how will we organize the sequence of learning?

What this type of assignment is doing is actually presenting teachers in the course with the opportunity to get acquainted with a different set of assessments than the traditional pencil and paper tests. It also helps expose teachers first-hand to models of alternative assessment that students at the secondary stage go through, namely 'thanniwiya amma'. At the STEM schools, for example, there are alternative assessment methods based on interdisciplinary capstone projects. Students complete a project each semester which counts for 60% of their final grade. The rest of the total grade is allocated to a 30% final content exam and a 10 % participation grade. Therefore, teachers need to understand and experience alterative assessment methods to appreciate its value over traditional tests. From a cognitive perspective, alternative assignments have various advantages and impacts on the level and depth of student learning. Throughout alternative assessments, learners use higher order thinking skills rather than just rote learning and memorisation. There is also emphasis on bringing about students' areas of strength as they are required to perform in authentic and realistic situations and perform on a range of activities. One main challenge that is observed in this assignment is that the teachers are finding difficulty with integrating engineering with the other disciplines of STEAM. It should be noted that engineering is not a subject presented in Egyptian school curricula; therefore, there is much resistance to include it in the integrated lesson plans. This seems to align with experiences of teachers in other studies (i.e. DiFrancesca, Lee, & McIntyre, 2014) who also found difficulty with integrating engineering.

CONCLUSION: STRENGTHS AND AREAS FOR IMPROVEMENT

Teachers come to the course with much interest in knowing about an innovative approach in education, especially one that has been used as a buzzword in the literature such as STEM/STEAM education. It is clear that what they are getting from the programme is not offered elsewhere. They start to get anxious that it might not fit with their school, having known the tight and centralised system in Egypt. Changing logistics at school such as class schedules or even getting teachers to plan together for their lessons is a practice far from the norm and teachers attending the PED STEM/STEAM track know this from their personal experiences. With a culture dependent on separate disciplines and where assessment represents a high stakes exam, little attention is given to the quality of learning and finding value and meaning as provided by STEM/STEAM education, since there is more emphasis given to grading and passing exams. Yet, after going through the course and experiencing a STEM/STEAM integrated framework, teachers begin to envision the need for such philosophy that stresses on higher order thinking skills and addresses issues related to the workforce and economic benefit of the country. This is truly seen as an opportunity to present quality education in Egypt; a point made clear from the outset and that aligns with the national view of science education in an integrated reform context with the expansion of STEM secondary schools.

While reflecting on the course, one of the areas that could be improved is the inclusion of school visits where teachers can see interdisciplinary pedagogies being implemented. The only school that implements STEM education in Egypt are the boys and girls STEM school for the gifted. Although there is a reservation on how ‘gifted’ is defined in this context, in addition to including one sector of students to this type of education and excluding others, this is the only option available so far. The other point that could be of benefit to the course and for the schools in the future, whether STEM/STEAM school or even the national schools in Egypt, is to invite various stakeholders to enrol in the course. What is meant by stakeholders is school administrators, parents, board of trustees, senior and junior teachers to all attend and be accustomed to such innovative teaching that requires support and understanding from the whole context to ensure a sustainable change needed for the country and its future generations.

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PART II

DISCIPLINE-SPECIFIC SCIENCE METHODS COURSES

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6. DEVELOPING A REPERTOIRE FOR TEACHING BIOLOGY

INTRODUCTION

In this chapter we describe the rationale and design of a biology method course for preservice biology teachers who are enrolled in the teacher education program at ICLON, Leiden University Graduate School of Teaching in the Netherlands. Before we provide a more detailed course description we will briefly describe the Dutch teacher preparation context. In the Netherlands, there are two different structures to prepare teachers for secondary education: undergraduate programs provided by universities of applied sciences, and post-graduate teacher preparation provided by research universities, like Leiden University. The universities of applied science provide a four year undergraduate program which includes courses on subject matter as well as pedagogy. This program prepares for teaching in lower secondary education (up until Grade 9).

The research universities provide a post-graduate teacher education program lasting one year that leads to a qualification to teach all levels of secondary education. Previous to enrolling in these teacher education programs, participants obtained a Master's degree in the discipline they are going to teach at school. The structure of the program at ICLON includes courses, one day per week at university, plus about 10 hours per week practice teaching at a secondary school under supervision of their placement tutor. The university provides cross-curricular courses on topics such as teaching strategies, classroom management and adolescent psychology. Additionally, the program includes basic and advanced subject-specific method courses both consisting of 9 meetings (3–4 hours per class meeting). Because preservice biology teachers attend courses at the institute and teach at school as well we are able in our course to build on their teaching experiences and to provide conceptual and practical tools for designing (some of the) lessons they will enact at their school.

PLANNING: DISCUSSION OF COURSE DESIGN

In line with the classic proverb that many roads leads to Rome, there are many ways of high quality biology teaching. We believe it is therefore better to replace the common question "What is the best way to teach topic x in biology education?" by

A. J. Sickel & S. B. Witzig (Eds.), Designing and Teaching the Secondary Science Methods Course, 91–107.

the question "How can preservice biology teachers develop their teaching repertoire to allow them to teach biology in multiple productive ways?" A wide-ranging teaching repertoire, so called adaptive teaching expertise, enables teachers to respond flexibly to pupils' varying capacities and interests, to changing teaching contexts, approaches and content. Furthermore, teachers who are able to continuously develop their teaching repertoire are more likely to experience teaching as a challenging and fulfilling activity (Janssen, Grossman, & Westbroek, 2015).

Developing adaptive expertise requires a balance between the development of routines and innovation (Chi et al., 2011). Both a one-sided focus on the efficiency dimension, leading to boredom, and a one sided focus on innovation, leading to frustration and loss of control, is prevented this way.

Teaching repertoire development should enable teachers to implement a wide range of high quality teaching practices. Good teaching is where the three corners of the didactic triangle (teacher, pupil and content) are tuned to each other. In short: in good teaching, pupils acquire *exemplary* content, in a manner that builds on what a pupil knows and can do (*adaptive*) and which is *practical* for the teacher (Figure 1).

First of all, teaching content should exemplify the main ideas and ways of thinking of the discipline (Schwab, 1964) (see Table 7 exemplified in Figure 3). These fundamental ideas and perspectives are what enable the pupils to deal with future new situations and to go on studying more easily later on. As Peters (1973) once remarked, *"To be educated is not to have arrived at a destination, it is to travel with a different view"* (p. 10).

Secondly, the success of teaching critically depends on how it is adapted to the needs and potential of the learners (Table 1). Based on research on effective teaching from multiple perspectives we have summarized the main criteria for adaptive teaching (Corno, 2008; DeCorte, 2010; Muijs et al., 2014). A pupil only learns effectively when he/she is given the opportunity, wants to, is able to and when there is a certain sense of mutual trust. Two criteria can be identified for each of these main categories. We formulated them as questions pupils (i.e., secondary school students) should be able to answer affirmatively after having followed the education concerned.

And finally the design and enactment of the teaching practice should be practical for teachers. Doyle and Ponder (1977) pointed out that teachers do assess educational proposals on their practical usefulness. Proposals which are found practical are likely to be robustly implemented. Proposals which are found impractical are turned down or made into practical ones by teachers in their classroom, though this usually detracts from the essence the educational proposals. Teacher will only consider a new teaching practice practical if cost-effective procedures are available to translate innovative ideals into concrete instruction and if the proposed changes sufficiently fit the teacher's current practice and goals (Doyle & Ponder, 1977; Janssen et al., 2015).

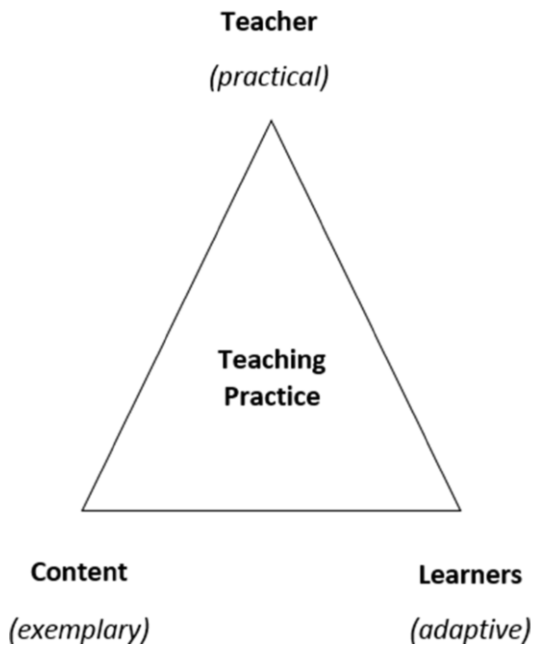

Figure 1. High quality teaching practice is adapted to what individual learners need, exemplifies the core ideas and ways of thought of the discipline and is practical for teachers

Table 1. Criteria for adaptive teaching formulated in questions that pupils should be able to answer affirmatively

	Criteria	
Opportunity	Purposeful	Were you able to practice what you have to be able to do?
	Clarity	Did you know what was expected of you?
Wanting	Interest	Did you think it was interesting?
	Expectation of success	Did you think you would be able to do it?
Being able	Challenging	Was it too easy, or too hard for you?
	Adaptive support	Did you get the help you needed (not too much or too little?)
Trust	Respect/care/understanding	Did you feel taken seriously?
	Autonomy	Did you have freedom of choice? Did you feel in control?

Against this background the question becomes how preservice biology teachers can develop high quality teaching repertoire step by step, building on already existing routines. The two main ingredients are on the basic and advanced biology method courses (each consists of 9 meeting, 3 or 4 hours per class meeting) and the lessons our preservice teachers teach at school (on average 10 hours a week). To develop their repertoire teachers will repeatedly go through a cycle of designing and enacting lessons, looking back on their experiences and what they learned from them, which results in new intentions, based on which they can go through the cycle again (Figure 2). In the course meetings we support preservice teachers to design their lessons. In these lessons they try to incorporate new ways of teaching learned in the course (see Table 5) and they enact these lessons in their own classes at school. In the course meeting we also stimulate them to reflect productively on these teaching experiences.

This notion of developing the repertoire by a cyclic process of designing, executing and reflection on lessons is not a novelty of course (see Dewey, 1910). In these reflection cycles, teachers are stimulated to look back on their experiences and to identify what they have learned. Moreover they are invited to apply what they have learned by formulating resolutions, and design and enact lessons in practice that incorporate these resolutions.

However, we add three elements here which makes cyclic reflective learning more motivating and productive (Janssen & van Berkel, 2015).

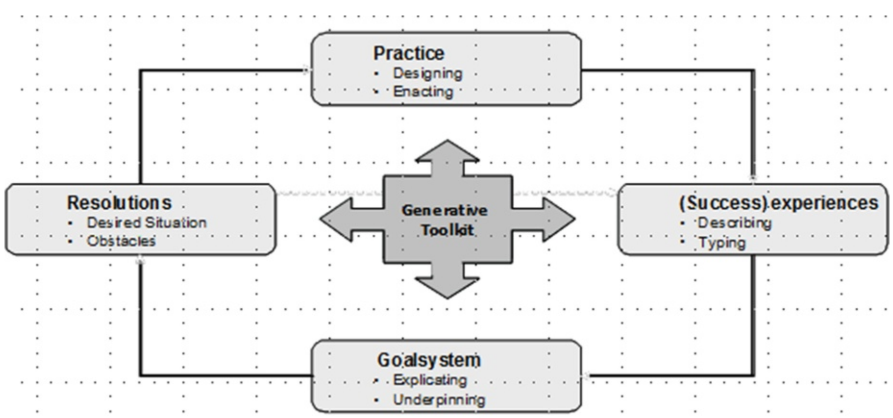

Figure 2. Developing your teaching repertoire by cyclic reflective learning from experience

Toolkit

Our most important addition to the reflective cycle is what we call a generative toolkit. This toolkit consists of theory-based building blocks and rules that preservice teachers can use to (re)design challenging and adaptive lessons in a practical way by recombining and adapting existing lesson building blocks. We put this generative toolkit at the centre of the reflective cycle because it not only supports the design of lessons, but it also helps preservice teachers to reflect productively on their teaching experiences and with formulating new learning intentions. In other words, the toolkit supports teachers to continuously discover new choices and possibilities concerning the *what* and *how* of the lessons. The toolkit helps teachers to stepwise expand their repertoire of challenging and adaptive lessons.

Later in this section we describe in more detail the nature and content of this toolkit.

Successful Experiences

A second element we wish to stress is the importance of learning from successful experiences (Janssen et al., 2009). In reflective experiential learning, usually learning from mistakes is emphasized. Research shows, however, that it is often hard for teachers to get to productive intentions by reflection on problematic experiences, and being motivated to execute them. In many cases, reflection on problematic experiences results in intentions to avoid such situations in the future. However, if teachers look back on teaching they experienced as successful, this usually results in much more productive and innovative intentions, and they tend to be more motivated to execute these on top of that.

Goal System

The third and last element we add to the regular reflective experience cycles is the goal system as a means of demonstrating compactly what a teacher does and why s/he does it like that. Goal system theorists emphasize that a person's actions in complex situations are often guided by multiple goals simultaneously organized in a goal-means hierarchy and competing for limited resources (Fishbach, 2007; Shah & Kruglanski, 2008). A teacher's goal system represents his/her model practice of teaching, and therefore directs his/her design and enactment of lessons (Janssen et al., 2013) (see Figure 4 for an example of a teacher's goal system).

Summarizing: with the help of the generative toolkit and support of the teacher educator in the biology method course preservice teachers can develop their teaching repertoire step by step by formulating intentions, detailing these into concrete lessons, enact them in his/her school, learning again from successful experiences, elaborating or adapting their goal systems which in turn results in new intentions et cetera.

Before we will illustrate this approach with a case, we describe in more detail the nature and content of the generative toolkit, including the way how elements of the toolkit and related possibilities for design and enactment are introduced step by step in the successive meetings of both the basic and the advanced biology method course.

Our main inspiration for developing a generative toolkit comes from modular innovation in both the man-made (language, cars and computers et cetera) and natural world (like evolution) (Janssen, Grossman, & Westbroek, 2015). All kinds of modular innovation are based on a limited set of building blocks (for instance our Roman alphabet and our genetic alphabet) and a limited set of rules that determine which recombinations of building blocks are viable and which are not. Such systems are sometimes labelled with the term *generative toolkit* because an enormous diversity of innovations can be generated with a limited set of building blocks and rules.

Over the years, the first author has developed and tested a generative toolkit for stepwise development of a teaching repertoire (Janssen et al., 2013b; Janssen & van Berkel, 2015). The basic set consists of four building blocks (explanation, worked out example, whole task and part task; Table 2). Teachers can redesign their lessons both by selectively omitting building blocks and by changing the sequence of the building blocks. The basic set also consists of two rules for selecting and recombining building blocks (whole task first and adaptive support; Table 3). With this basic generative toolkit teachers can expand their repertoire of challenging and adaptive teaching by reversing and selectively omitting existing lesson building blocks. Table 4 shows a concrete illustration of a teacher redesigning a lesson on how the ear works in this way. We refer to Janssen and Van Berkel (2015) for an in depth theoretical discussion of the generative toolkit.

Table 2. Building blocks of the generative toolkit for teaching: Basic set

Building block	*General description*	*Example*
Explanation	The subject matter is presented in general terms.	The teacher explains the structure of the ear and how it works.
Worked-out example	The subject matter is illustrated or demonstrated by an example.	The teacher describes what happens in your brain and ears when you experience 'ringing in the ears' after having listened to loud music.
Whole task	An assignment challenging pupils to use the core of the subject matter in a new situation.	Vincent van Gogh cut off his auricle. Pupils are asked if his hearing is better or worse and how this can be explained with the help of knowledge about the structure of the ear and how it works.
Part task	An assignment demanding pupils to reproduce or apply a small part of the subject matter that needs to be covered.	Pupils are asked to explain the nature of the hammer, anvil and stirrup, and what would happen if the stirrup was missing.

Table 3. Rules of the basic generative toolkit for teaching

Rule	*General description*
Whole task first by reversal	Start the introduction of new subject matter by introducing the whole task. Usually, an existing whole task can be brought forward to this end (reversal) (see example of Vincent van Gogh, Table 4)
Adaptive support help by selective omission	Consider everything you normally offer and do in class as help for doing the whole task. Give pupils only the help that they require (selective omission.)

Table 4. Making a lesson about the ear challenging and adaptive by reversal and omission

Before
The teacher first explains the new subject material about the structure of the ear and how it works. Then the pupils start their part tasks associated with the subject. In conclusion of the class, the teacher brings up the example of the 'ringing ears' and he asks his pupils whether Vincent van Gogh would hear better or worse after having cut off his auricle.
After reversal and omission
Whole task first The teacher starts his lesson on the ear by introducing Vincent and his cut-off auricle and invites his pupils to discuss for two minutes if his hearing is better or worse, and why?
Adaptive support After the introduction of Vincent, pupils have a choice. They can either start with this task immediately, with just the ear diagram from the textbook to help them, using all terms mentioned in the diagram in their answers to the question. Or they can listen to the teacher's explanation about the structure of the ear before tackling the Vincent assignment.

With only four building blocks and two rules a vast repertoire of challenging and adaptive biology lessons can be designed. The lesson example we just showed is relatively simple in design. The teacher determines the whole task, this task is about a limited amount of subject matter and the options concerning adaptive support are also limited. However, the two rules and four building blocks can also produce different and more complex forms of teaching depending on the amount and nature of the content covered by the whole tasks and to what extent pupils have a say in determining the whole task(s) they are working on. Moreover, adaptive support can be implemented in various forms depending on who controls the adaptive support, how much support is provided and to what extent the support is personalized.

Two expansion sets of building blocks support the teacher to diversify and specify choices concerning the what and how of the whole task and the adaptive support. One set of building blocks is derived from generic theoretical perspectives on teaching and learning (like behaviourism, constructivism, situationism et cetera) (see Table 8). In addition we have developed a domain-specific set representing the core perspectives, questions, methods and fundamental principles of the life sciences (see Table 7; exemplified in Figure 3). These five biological perspectives and related questions (what is it?; how did it evolve?; what is it for?; how did it develop?; how does it work?) are derived from the work of Nico Tinbergen (1963) and updated with new methodological insights about what kind of questions biologists ask and how they try to answer these questions (Bateson & Laland, 2013; Wimsatt, 2007; Bechtel & Richardson, 2010).

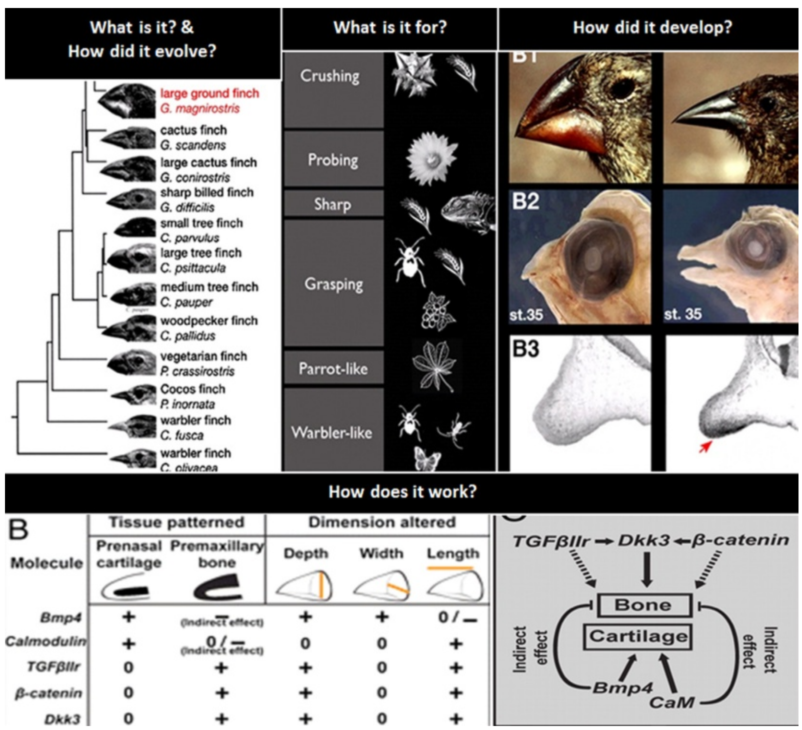

Figure 3. Four perspectives on life phenomena exemplified for Darwin's finches. Darwin's finches are a group of fourteen species. They are classified as the subfamily Geospizinae (what is it?). Their common ancestor arrived on the Galapagos islands about two million years ago (how did it evolve?). The astonishing variation in the shape and beak of Darwin finches reflects a wide range of dietary specializations (what is it for?). Beak shape and size is established by two different developmental modules (how does it work?). Multiple molecules regulate these two modules and can independently alter growth along different axes (how did it develop?). Images are adapted from Mallarino et al., 2011; Rands et al., 2013

Table 5. Outline of the basic and advanced biological method course

Meeting	*Introduction of the parts of the toolkit/Key assignments*	*Biological topics*
Basic Course		
1	Designing a whole task first lesson by reversing (direct instruction lesson)	Organ systems
2	Designing a whole task first lesson + Using the other biological perspectives	Organ systems
3	Using the functional perspective to structure an instructional explanation.	Organ systems and ecology
4	Eliciting and taking into account pupil misconceptions in the context of a whole task first lesson. Using general teaching and learning perspectives	Genetics/Metabolism/ Photosynthesis
5	Designing formative and summative assessments	All topics
6	Supervision/Eliciting your goal system	All topics
7	Designing adaptive support	All topics
8	Orchestrating a classroom discussion on a difficult and/or controversial topic	Evolution
9	Designing and implementing adaptive support (part 2)	Genetics
Advanced Course		
1	Supporting learners to make complex task (metacognitive and domain specific skills).	Topics from the final national school exam
2	Learning by designing. Supporting learner's biological modelling using the functional perspective	Immunology/Ecology
3	Designing and implementing whole tasks and adaptive support that cover a whole chapter	Reproduction and Sex education
4	Converting a cookbook lab into an open inquiry lab	All topics
5	Design and implement a meaningful fieldwork for learners.	Ecology and Environmental education
6	Let learners develop knowledge using perspectives as tools for thinking.	Topics are viewed from all perspectives
7	Alignment and integration between the STEM subjects.	Interdisciplinary topics
8	Analyzing the biology curriculum using the perspectives	Connections between topics and alternative curriculum structures
9	Articulating your goal system learning path and teaching repertoire, again, and relate it to the building blocks of the toolbox.	All topics

With the basic and advanced generative toolkit preservice teachers can continuously develop their repertoire by selecting and recombining building blocks while building on previous successful teaching experiences.

In both the basic and advanced biology method course preservice teachers are introduced step by step to elements of the generative toolkit and the related possibilities for the design and enactment of biology lessons. The preservice teachers come to the methods courses with content knowledge in biology from prior study. But of course they learn (and need to learn) more biology content when they design lessons about specific topics. Therefore elements the generative toolkit are exemplified by certain biological topics.

In Table 5 we describe in more detail in what order elements of the generative toolkit are introduced. We have formulated these elements in terms of the key assignments for preservice teachers for every meeting. The biological topics which exemplify these elements are listed in the right column of Table 5. The sequence in which the elements of the toolkit are introduced is based on three simple-to-complex learning progressions (a) starting with more teacher-centered lessons, working towards more pupil-centered and adaptive lessons; (b) starting with a lesson as a unit of analysis to bigger units like lesson series and the curriculum as whole); (c) starting with using biological perspectives only as tool for designing lesson towards supporting learners to use biological perspectives themselves.

In the two courses spanning one year, preservice teachers develop their repertoire by selecting and recombining building while building on previous successful teaching experiences. In the sections on vignettes of teaching and assessment we will describe and illustrate in more detail how this will work in practice.

CLASSROOM PRACTICE: VIGNETTE OF A SIGNATURE LESSON

We will now demonstrate with a case study of a preservice biology teacher, Ilse, how preservice teachers in our course use the generative toolkit, including the two expansion sets, for shaping their own learning route for developing their teaching repertoire related to the course meetings as described in Table 5. As we already indicated earlier we aim for a learning pathway where a teacher builds step by step on what he/she already knows and can do, so the teacher will stay in flow and avoid both the sense of loss of control and boredom.

We now briefly describe a part of Ilse's learning pathway, starting by a short characterization of her initial situation. We use a so called laddering interview in our course to co-construct a teacher's goal system to characterize a teacher's initial situation. We will first describe the laddering interview procedure and then describe and explain Ilse's initial goal system. The interviewer, either the teacher educator or another preservice teacher, only needs a A3 sheet and a bunch of post-it notes

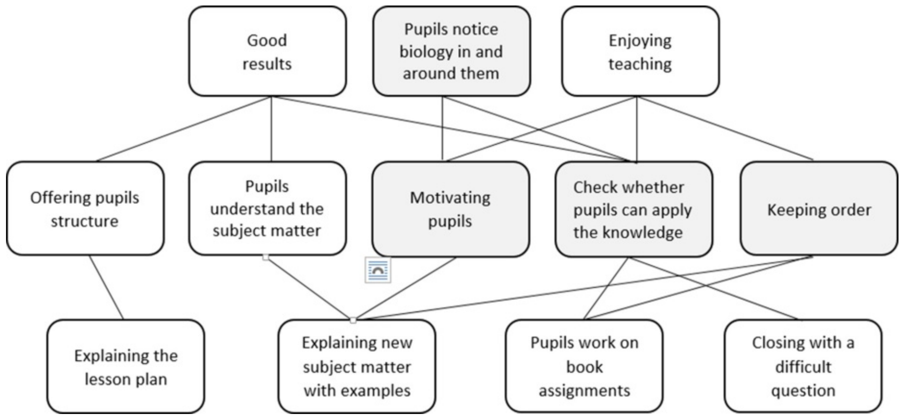

Figure 4. A teacher's goal system

(see Janssen et al., 2013 for a detailed description and justification of the laddering interview).

The laddering interview will proceed as follows:

1. The interviewer asks the teacher to bring a representative lesson to mind, and then describe what he or she does in such a class, and in what order ('from bell to bell'). The interviewer writes every part of the class on separate post-it sheet, in the teacher's wording (the bottom row in Figure 4).
2. Then the teacher is invited to state for each part why he or she thinks this is important. These answers are also taken down literally on separate post-it sheets and stuck unto the A3 sheet. Every part of the class can contribute towards several goals. Every goal – means relation is connected by an arrow. The interviewer can ask more questions about each goal, why the teacher thinks this goal is important, until the teacher has 'arrived' at his/her most important goals (top row in Figure 4).
3. Finally, the teacher is asked to indicate – with a colour or a symbol – which goals from the goal system were realized satisfactorily (white blocks in Ilse's goal system) and which targets were not met as well (grey blocks in Ilse's goal system)

Ilse's goal system indicates clearly how her classes used to proceed in the first months of her teacher education program. After Ilse's explanation of the new subject material, pupils would start doing assignments from the work book. Ilse used to end the lesson by asking a difficult question, to see if the pupils were able to apply the material. She was generally quite happy with this approach, but it bothered her repeatedly that some pupils were not paying attention during her explanation. She

Table 6. Five steps in Ilse's learning pathway. She herself has formulated this pathway

Step	*Related course meeting*	*Intention and Teaching Experiment*	
1	Basic course meeting 1, 2 & 3	Intention	I would like to try whole task first lesson by reversal
		Teaching experiment	An ecology class which I 've ended in another group by challenging the pupils with the following statement by a Dutch politician Marianne Thieme: "A vegetarian in a Hummer is more environmentally friendly than a 'meat eater' on a bicycle", I now start with this statement, and they start working on it after the explanation.
2	Basic course meeting 4	Intention	I would now like to start with real-life context and try the master-apprentice approach next.
		Teaching experiment	The class on photosynthesis starts with a horticulturist's issue of wanting to up his production. I use this case to for explaining photosynthesis. Then the pupils have to come up with an experiment in which they can demonstrate photosynthesis.
3	Basic course meeting 7 & 9	Intention	I want to let pupils choose between direct instruction and guided discovery.
		Teaching experiment	Pupils are assigned to design an artificial heart. They have a choice whether to listen to the explanation first, or immediately start off with the functional strategy.
4	Advanced course meeting 2 & 3	Intention	I have noticed that a complete task instruction is essential for discovery learning.
		Teaching experiment	In a parallel class I taught the same lesson, but now I indicated much more clearly what they have to do, with whom, how, and what they have to deliver at the end.
5	Advanced course meeting 6 & 8	Intention	I want to acquaint pupils with different ways of biological thinking
		Teaching experiment	In the framework of a series of lessons about evolution, pupils could choose an animal and an interesting trait. Then they question the chosen theme from four perspectives, producing a kind of collage with captions, and formulate and visualize the answers by consulting various sources (see Figure 3 on the Darwin finches as an example)

had to warn regularly and sometimes ended the explanation part early and let the pupils work by themselves. She also regretted the fact that she had not yet been able to put an important goal of hers into practice. She was under the impression that the pupils viewed biology as something from a book, rather than realizing it is constantly present in themselves and their surroundings.

She started to develop her repertoire step by step, partly related to new possibilities of newly introduced aspects of the generative toolkit in the course meetings (Table 5), ever building on what she was already doing and using the positive experiences from adaptations she had applied. In Table 6 she herself describes five important steps from her learning pathway and relates this to particular meetings of both the basic and advanced course (second column from the left in Table 6). For every step she stated her intention as well as lesson(s) she designed and enacted based on her intention. These lessons we call teaching experiments.

This learning progression shows how Ilse stepwise developed her repertoire using the toolkit. For instance in the first two meeting the first rule of the basic generative toolkit is introduced and demonstrated: whole task first principle by reversal. Ilse decides to use this rule to adapt her ecology lesson that she already taught in her regular way (explanation first) for another group of pupils.

ASSESSMENT: VIGNETTE OF A SIGNATURE ASSESSMENT

We consider the development of a practical, adaptive and theoretically underpinned repertoire for biology teaching as the overarching goal of the biology method course and related lessons taught at school. As part of our assessment procedure we therefore ask the preservice teachers to document their intentions and teaching experiments in a concise way as was demonstrated in Table 6. Moreover, they need to describe and explain their goal system twice during the biology method course.

Table 7. Typing of each step of the learning sequence with biological perspectives

Subject perspective	*Question type*		*Methods for*	
Taxonomic	What is it?	5	Classifying	
Functional	What is it for?	3 5	Functional analysis	3
Mechanistic	How does it work?	1 2 4 5	Discovery of a mechanism	3
Ontogenetic	How has it developed?	5	Discovery of development pattern	
Evolutionary	How has it evolved?	5	Evolutionary reconstruction	

For the basic course they should describe and justify in more detail two lessons (design, enactment and reflection) of which one lesson is enacted on video as well. For the advanced course they should describe and justify in detail a unit of lessons, with one lesson enactment recorded on video. For both, a report should be included on their pupils' learning outcomes based on formative or summative assessments and pupils' learning experiences. Therefore preservice teachers ask their pupils to fill in a short survey based on Table 1. Finally, preservice teachers should be able to typify and justify their vision on teaching and their learning pathways in

Table 8. Typing of each step with general teaching learning perspectives

Teaching perspectives	*Building blocks for WHAT is important to learn*		*Building blocks for HOW to learn from a positive motivation (Italic)*	*T3*
Behaviorist	Facts and procedures	1	Explanation and exercise with feedback *(reward)*	1
Constructivist	Concepts and strategies	3	Guided discovery based on what you know and can do *(interest)*	3
Socio-cultural	Competencies to partake in social practices	2	Copying from example and participating with decreasing help *(role identification)*	2
Personalistic	Self-knowledge and self-esteem		Reflective experiential learning in a safe environment *(confidence and self-confidence)*	
Outlook on Life	Values and an outlook on life		From traditions, by example and through dialogue *(meaningfulness)*	
Critical	Social criticism and social action		By ideology criticism and social action *(justice)*	
Self-regulation	Learning to learn		Guided planning, executing and evaluating of a learning process *(self-effectivity and self-control)*	
Ecological	Learning what is expected of you in class	4	By whole task instruction (who does what, how and when) *(clarity)*	4
Interpersonal	Social skills		By observing, and adjusting your behaviour *(connectedness/influence)*	
Academic rationalist	Perspectives (ways of knowing and thinking)	5	By critical examination of underlying assumptions *(wonder)*	
Bounded Rationality	Efficient procedures (heuristics)		By example, copying and feedback *(practical usability)*	

terms of general perspectives on teaching and learning and in terms of biological perspectives. In Table 6, Ilse characterizes important steps (1, 2, 3, 4 and 5) of her learning pathway. In Table 7 her learning pathway is characterized in terms of changes in using biological perspectives and in Table 8 in terms of changes in using general perspectives of teaching.

CONCLUSION: STRENGTHS AND AREAS FOR IMPROVEMENT

The rationale and design of the biology method course described here is the result of 15-year design research project. In design research both an intervention and the underlying theory are developed simultaneously in a spiral process of theoretical reflection, design and testing (see Janssen et al., 2013b for description of the main research phases and empirical and theoretical results). The primary aim was to develop an approach that supports biology preservice teachers in developing their teaching repertoire. The secondary aim was to contribute to the development of theory concerning how biology preservice teachers develop their repertoire and how this can be supported. These theoretical reflections were intended to underpin our method and explain the effects observed. We have made considerable progress with respect to both overarching aims. Many research projects on various aspects of our course have demonstrated that the generative toolkit supports preservice teachers to continuously develop their repertoire of high quality teaching practices by selecting and recombining existing lesson building blocks while building on previous successful teaching experiences (see Janssen & van Berkel, 2015 for an overview). Moreover this long term design research project has also resulted in productive theory development on teacher practical decision making and learning (see also Janssen & van Berkel, 2015 for an overview).

Although this design research started 15 years ago it has not been finished yet. The strength of our course is its focus on design. The toolkit supports preservice teachers to (re-)design their lessons in a practical way. However, less attention has been paid to supporting preservice teachers to enact interactive core teaching practices like orchestrating a classroom discussion; creating a classroom culture and helping pupils work together et cetera. We have already explicated the theoretical foundations for integrating design and enactment aspects of teaching (Janssen, Grossman, & Westbroek, 2015), but it will take some more time to actually work this out in practice.

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7. EDUCATING BIOLOGY TEACHERS FROM A SOCIO-CULTURAL PERSPECTIVE

Experiences in a Public University in Brazil

INTRODUCTION: CONTEXT

In this chapter we describe our experiences as a team of professors working in a Biology Teacher Education Program at a public university[1] in Southeast Brazil, the Universidade Federal de Minas Gerais (UFMG). The program is coordinated by the Biological Sciences Institute (BSI), in collaboration with the College of Education (CEd). Prospective biology teachers (PBTs) graduating from this program can teach biology at the high school level as well as general science in 5th–9th grades.

In the last decade, Brazil's performance in international evaluations, like PISA, evidences that changes in science education were in course. For instance, from 2006 to 2012, there was an increase in enrolment of about 425 000 students at the age of 15, who come mainly from rural communities or who are socioeconomically disadvantaged (OECD, 2015, p. 4). Moreover, lowest-performing students were the ones who presented major gains in performance (OECD, 2015, p. 3). In parallel, other studies show that Brazilians not only consider science an important endeavour and have great interest in issues related to it, but they also have positive attitudes toward science and technology (InCITE, 2015). However, there is much room for improvement, considering that 61% of students have only very basic science understanding (OEDC, 2015, p. 3). Various causes are attributed to this problem, some related to broader contexts (e.g. great social inequalities, leading to inequalities in access to education; strong influence of religious groups, leading to controversy around teaching about evolution) and others more specifically related to education (e.g., limited investments in education; challenges in teaching career like salary, working conditions, and professional development opportunities).

The first national standards were elaborated in the 1990s, and were informed by a constructivist perspective, encouraging new approaches to teaching. However, these standards worked only as guidelines for states and counties to elaborate their curricula and evaluation. Currently, a Brazilian national curriculum is under elaboration, and should be submitted to approval by 2017. State Standards were elaborated in 2000s–2010s, and since then, national and state assessments were implemented to

A. J. Sickel & S. B. Witzig (Eds.), Designing and Teaching the Secondary Science Methods Course, 109–127.

promote alignment and to evaluate students at all levels (e.g., Bonamino & Sousa, 2012).

Teacher Education Reform

The UFMG Program and the Methods course that we describe in this chapter were created in 2005, following guidelines of a 2002 educational reform (Barreto, 2015).[2] In an effort to challenge the prevalence of traditional teacher-centred approaches, a key concern that oriented the 2002 Teacher Ed Reform was to promote stronger relationships between theory and practice (e.g., Korthagen & Kessels, 1999; Zeichner, 1999). Science Teaching programs have been particularly affected by the lack of integration between knowledge in fields of science with knowledge about teaching (NRC, 2001; Shulman, 1986). Considering this goal, programs were required to focus on changes in three aspects: (i) courses that address teaching/education occur earlier in the program; (ii) more courses to provide opportunities for establishing relationships between subject matter knowledge learning and learning about teaching (NRC, 2001), as well as integrating academic knowledge to teaching practice at school (Ingersoll & Strong, 2011); and, (iii) an increase in Practicum courses (Ingersoll & Strong, 2011).

The UFMG Biology Teacher Education Program: An Overview

Only a few decades ago, scholars across the world initiated appropriate investigation to explore complexity of knowledge about teaching. These investigations had a key role in promoting changes in how we educate biology teachers (Zeichner, 1999). In Brazil, as in many countries, before the 1980s there was a consensus that experts (e.g., university professors, scientists) should be responsible for designing Teacher Ed Programs, considering the prevalent view of knowledge about teaching as "technical." At that time, great criticism to teachers' practice oriented Teacher Education, positioning knowledge coming from practice (i.e., teachers' knowledge) as "inferior", less elaborated than expert/academic knowledge. Moreover, teacher knowledge was considered unproblematic, and teacher learning was seen as a process of transmission, not meaning making. Both the complexity of knowledge about teaching and the difficulties to establish relationships between theory and practice pose great challenges to teacher educators. The effect of participation in Teacher Ed Programs is still contentious (e.g., Zeichner, 1999).

Certain aspects of the structure of UFMG Program (presented in Table 1) represent an effort to challenge this separation. A significant part of the Program involves Methods courses and Practicum courses. Topic specific Methods courses are offered at the BioSciences Institute (BSI) under the responsibility of professors who have expertize in biological research and little or no experience with K-12 teaching nor with educational research. Whereas, Practicum courses and Biology education Methods (BioEd Methods) courses are offered at the College of Education

Table 1. Main Courses/Activities that compose the UFMG program of science and biology teacher education

Type of Course	*Examples of Courses*	*Hours*	*College*
Content Courses common to BS students and PBTs	Invertebrate Zoology I; Ecology; Plant Physiology	1530	BSI
Content Courses specific to PBTs	Physics, Human anatomy, Applied Physiology	165	BSI
Educational Theory Courses	Sociology of Education, Educational Policy, Psychology, Didactics	240	CEd
Topic-specific Methods Courses	Laboratories of Teaching: Botany, Ecology, Health, Physiology, Genetics, Zoology,	225	BSI
Biology Education Methods Courses	Didactics of Science and Biology I and II	60	CEd
Practicum- Internship (Time at School)	Analysis of Classroom Practice I, II, and III	60+405	CEd – K-12 School
Scientific Academic Activities	Internship in laboratories, participation in lectures	90	Open

(CEd) by our team of professors,[3] all with PhDs in Science Education and K-12 teaching experience (Table 2). They are sequenced, planned and taught in a way that learning about theories/discussions that emerge from the field of science education research is intertwined with experiencing science teaching at "regular" schools – and reflecting about these experiences (Schon, 1983). Explicit teaching related to academic knowledge in science education takes place mainly in BioEd Methods Courses, whereas issues related to experiences at school (e.g., individual reflection, discussions, planning, supervision) are systematically addressed in Practicum courses. In this chapter we will address the BioEd Methods course I (Table 2).

THE METHODS COURSE "TEACHING SCIENCE AND BIOLOGY I"

PBTs in UFMG program, usually, had a teacher-centred and information-centred education, involving static ways of interacting with teachers, peers and resources. As the literature reports, past experiences of teachers strongly shape their views of learning, learning to teach, and their ways of teaching (e.g., Loughran, 2007). Informed by a sociocultural perspective (e.g., Putnam & Borko, 2000; Ellis, Edwards, & Smagorinsky, 2010) our main goal in BioEd Methods courses is to introduce ideas that can support PBTs in understanding biology learning as a social process that involves being introduced to practices of scientific community (Driver et al., 1989) and that is situated in contexts in which they are constructed (Brown

Table 2. Overview of the courses related to biology education that are offered at the college of education

Semester	*Practicum course*	*Methods Course*
6th/7th	*Critical Analysis of Pedagogical Practice I* (60h at school, 30h at university) Short-term school/classroom observation: contrasting schools. Reflective journals. Seminar relating experiences at school and academic research	*Teaching Science and Biology I* Focus on knowledge about learner: e.g., students' conceptions, students characteristics
7th/8th	*Critical Analysis of Pedagogical Practice II* (150h at school, 30h at university) Observation and support to the mentor teacher in a K-12 classroom during science lessons. Planning and teaching few lessons. Reflective journals. Investigative project using evidence collected in the classroom.	*Teaching Science and Biology II* Focus on teaching: e.g., science curricula; approaches to science teaching; argumentation, scientific language.
8th/9th (last)	*Critical Analysis of Pedagogical Practice III* (200h at school, 60 at university) Planning and teaching a science unit with an innovative approach. Reflective journals. Seminar presenting science unit.	

et al., 1989), involving also issues of power, class, ethnicity, and history (Bloome & Clark, 2006).

This perspective on biology learning at school becomes more concrete with Duschl's (2008) view of science education as a "Three-Part Harmony", based on conceptual, epistemic, and social learning goals. He emphasizes the significance of "engaging learners in conversations examining 'science-in-the-making' practices", considering that in these situations "important dialectical discourses about data representations, data and conceptual models, evidence, explanatory theories, and methods are incorporated into science learning environments" (p. 13). Thus, in BioEd Methods courses, we expect PBTs not only to develop strategies to teach considering these multiple goals, but also gain an understanding of the academic knowledge in different fields that supported it (e.g., establishing connections between learning theory and science education). Consequently, discourse is a key theme in the course. Moreover, PBTs not only read studies and essays about science classroom discourse and analyze science classroom discourse, but they are also expected to engage as learners in different discursive practices and reflect about consequences of different forms of participation (Putnam & Borko, 2000).

In this chapter, we focus on BioEd Methods course I. The topics, activities, and assignments of this course (Table 3) are selected and organized mainly to support PBTs in acknowledging the role of K-12 students as *active learners*. However, this structure is also informed by goals of the Program, and, consequently, by what is addressed in other courses (Tables 2 and 3).

At the beginning of the course we address briefly issues of scientific literacy. The emphasis is in understanding the notion of *science education for all* (e.g., AAAS, 1989; Barton, 1998), and implications of this perspective to biology teaching. We believe that this notion is central for valuing students' knowledge. The second topic addressed in the course is students' alternative conceptions and everyday knowledge about biological phenomena and concepts. PBTs should have a notion of the nature and complexity of students' knowledge with concrete examples, examining the different theoretical perspectives on this issue. Then, we move to discussions about diversity and students' participation in other settings (e.g., religion, family, work). Our goal is to engage PBTs in reflections about how biology teaching and learning, are permeated by multiple contexts that students, teachers, school, etc. bring into the classroom (e.g., Bloome, 2012). Finally, the last topic addressed is the role of

Table 3. Overview of topics, activities, and assignments in BioEd methods course I and examples of how they connect with activities in other courses

Topic and issues addressed	*Activities and assessment*	*Connections*
Scientific Literacy rationales for teaching science/biology; what to teach in biology; changes in biology curricula through time	Readings* (e.g. Millar, 2014; Krasilch, 1994); Written essay; Classroom and online discussion; Analysis of different rationales for science teaching.	Methods II: Analyses of Curricular Guidelines
Students' Conceptions (SC) nature of SC about biological phenomena; how SC influence biology learning; everyday and scientific knowledge; conceptual profile	Readings (e.g., Miras, 1998; Santos, 1990; Mortimer, 1998); Planning and conducting lesson for assessing SC; Paper and poster presentation about lesson for assessing SC.	Methods II: Include lesson for assessing students' knowledge in an unit
Students' Diversity and Contexts class, gender, ethnicity diversity; teaching evolution and tensions with religion	Readings (Gomes et al., 2009, El-Hani & Sepulveda, 2009); Analysis of classroom interactions	Practicum I, II or III: journal on students' diversity (optional)
Classroom Discourse perspectives on learning: individual and/or social plane; role of language; perspectives on classroom discourse	Readings (Driver et al., 1994; Mortimer & Scott, 2003); Analysis of classroom interactions	Practicum I, II or III: journal on classroom discourse (optional) Methods II: contrast of everyday and scientific language

** Readings are all in Portuguese. Here, we give examples of analogous readings in English or refer to the original (in cases when we use a translation in Portuguese).*

discourse in science learning. Here, we explicitly contrast different theories about learning, emphasizing the role of language in social construction of knowledge in biology classrooms, and challenging both common notions of language as a static code and of communication as a process of transmission of information.

In this course, we use multiple instruments for assessment, like: (i) participation in class and/or in online forum in a weekly basis; (ii) questions and/or essays related to reading assignments; (iii) a written exam. However, in this chapter we will focus on major assignments: (i) investigation on students' conceptions; and (ii) Portfolio.

CLASSROOM PRACTICE: CREATING CONTEXTS FOR ARGUING ABOUT BIOLOGY LEARNING

In BioEd Methods I, we expect to create some controversy around "theoretical issues" to promote argumentation around biology teaching and learning. Argumentation has great potential to promote learning, including teacher learning (Andriessen, 2006; Zohar, 2007). Thus, every lesson (or sequence of lessons) follows a similar structure: (i) before class, PBTs are asked to read a paper that addresses the topic to be discussed, presenting contemporary perspectives on science education research community; (ii) in class, PBTs are confronted with situations (that take place in biology lessons) or statements/products (from students or teachers, textbooks) that problematize issues related to the topic; (iii) PBTs are asked to take positions in the debate and to support their claims/assertions; (iv) professor gives emphasis to ideas and perspectives from science education community, revisiting the reading(s) and, if possible, relying on elements that PBTs used to construct their arguments; and, (v) professor summarizes central ideas. Latter, different forms of assessment are used to help PBTs to situate knowledge about teaching biology in classroom contexts (e.g., transcripts, own experiences at school, data collected at school). In this chapter to illustrate this approach, we focus on lessons on two topics: (i) students' conceptions; and (ii) classroom discourse (Table 3).

Addressing the issue of students' alternative conceptions might be a "tricky" task. After taking a series of courses that defend a constructivist perspective, PBTs are familiarized with (or "enculturated" into) the notion that K-12 students bring their own knowledge to the classroom, and that it has a key role in learning. Thus, often, PBTs acknowledge the value of listening to students' ideas before teaching, and they are apparently open to include assessments of students' conceptions in their lessons. However, this attitude can be misleading, considering that studies indicate that teachers tend not to take into much account students' knowledge in their practice (e.g., Mortimer & Scott, 2003). Thus, when addressing students' alternative conceptions, it is fundamental to support PBTs in developing deep understanding of students' knowledge complexity.

The first reading assignment is a chapter on students' prior knowledge (Miras, 1998). Before class, PBTs participate in an online forum, responding to the question: "As teachers, why should we be interested in students' conceptions?"

For instance, a common answer is similar to that from Carla:

> I agree with my colleagues when they say that learning about students' prior knowledge is very important. It is based on this that we are going to define how to work with a topic in class, and when we should address it. It is very important to promote this initial contact of students with new content, even to measure his/her interest on the topic. That's the only way to define what is the best way to transmit the content to the student.

In this case, she emphasized the value of students' knowledge, but she also treated it as information to be used to find out how to "*transmit* knowledge", contradicting assumptions that students construct knowledge. Thus, this type of comment opens possibilities for discussions about the role of students' understanding, as well as for clarifying some assumptions of a constructivist perspective.

Other comments, like Melissa's, point elements in the reading that are significant for learning to teach biology:

> What I found most interesting in the text was not the topic per se, because it has been addressed in various moments. What I found interesting was the [discussion about the] importance of assessing students' prior knowledge. It was cool to see how to work with this knowledge; to understand how students use it in their lives; to know to what extent assess it, at what moment assess it when developing the content in classroom; and to know that only to learn about what students bring is not enough. We need to know what to do with this knowledge when we are working with a certain content.

Paulo, problematizes the notion of focusing on individuals to address prior knowledge, and he questions the value of educational theory for learning to teach:

> I think this idea about prior knowledge is awkward. How am I going to define what prior knowledge my student has if I need to think about 39 other students? I am not against developing a lesson that tries to access students' prior knowledge. But I found it difficult to imagine this in practice. I have the assumption that certain prior knowledge, that will orient my practice, is something more collective than individual. But the individual should be ignored? I am more concerned with the education that I will have, and with being ready to take the risks of teaching – and I don't think I am prepared for that – than relying on theories that only bring more and more theories. I rather have something more practical and that I can experience.

In class, the instructor presents some of PBTs contributions to create a context for them to engage in argumentation about students' misconceptions and the role of theory in teaching. For instance, in a scenario involving positions like those cited above, the main goal of the instructor turns out to be persuading PBTs to align with Melissa's ideas and to help them to be able to further develop these ideas (e.g., being able to give examples of "how students use their knowledge in their lives", and of "what to do with this knowledge when teaching certain content."). Moreover, the debate creates a context to provide evidence to challenge the position that educational theory is of little use "in practice".

As the debate progresses, positions and arguments need to be collectively organized. Mainly when PBTs have little experience in engaging in argumentation to learn, the instructor has to intervene more (e.g., requiring that they elaborate claims clearly, asking them to support their statements with data, citations, examples, and summarizing arguments). Nevertheless, the major role of the instructor is to introduce key knowledge derived from academic research. Thus her/his interventions are essential to problematize simplistic views of students' conceptions that PBTs might hold, and, at the same time, to help them to construct new possibilities for assessing students' knowledge as part of their teaching practice. In this specific case, the written text becomes an important tool in arguing (Lyne, 1990) – and PBTs also have to learn how to use it to participate in discussions. Thus, the instructor uses quotations to characterize the complexity of students' knowledge. For instance, referring to how various elements are intertwined in students' knowledge (e.g., dispositions toward learning; skills, tools, strategies for learning; knowledge about the topic) or how students' knowledge *about the topic* has also multiple elements (e.g., concepts; facts; procedures; norms; explanations; attitudes; personal experiences). Finally, in this lesson, the instructor must provide opportunities for PBTs to have contact with examples specific to biology.

The discussion of these aspects creates opportunities for PBTs to make sense of the complexity of students' knowledge and its implications for practice. PBTs can become more aware that they must pay attention to this complexity. Moreover, through this type of discussion it is possible to help PBTs to understand that "theory" and academic research is not meant to "solve" teaching problems, and that Teacher Ed does not provide a "menu" of ready made solutions, but engage prospective teachers in reflection and actions to make sense of how theory can support them in developing practices that help K-12 students to learn science in certain context(s).

This debate creates an appropriate context for, in the following lessons, broadening PBTs repertoire of examples of students' conceptions and ways of assessing them, and for introducing practical experiences at school – in this case, an investigation about students' misconceptions. In different activities PBTs have to reflect about: (i) the nature of students' knowledge; (ii) if they should be addressed in the individual plan or in the social plan; and (iii) the *nature of the interactions* they had to establish with these students to give them a voice.[4]

After discussing the following topic in the syllabus (i.e., issues of diversity and relationships between science and religion) there is a more explicit focus on classroom discourse (Table 3). These lessons are designed to support PBTs in becoming more conscious of the role of language use in learning. In the initial lesson around this topic, PBTs work in small groups to analyse transcripts of discursive interactions in different classrooms. What these lessons have in common is that, in different ways, teachers establish a dialogue with students, ask them to exam situations and take positions related to biological knowledge. Moreover, teachers introduce biological knowledge, relying on prior discussions. For instance, the following interaction (a short part of a transcript PBTs analyze), took place in a 6th grade adult education classroom,[5] when students were learning about ecological relationships[6]:

Teacher:	Can you think about an example of Mutualism?
Joaquim:	Spur-winged plover
Teacher:	And who?
Joaquim:	Crocodile
Teacher:	I wonder if they can live apart from each other? Do you think the plover can get food in a place other than there, in the mouth of the crocodile? And the crocodile can live without the plover?
George:	What is the name?
Teacher:	Spur-winged plover. There is a relationship. You probably saw it before. When the crocodile had just finished eating, it opens its big mouth full of teeth and stays still. Then, birds that have slim beaks come. They pick pieces of meat in crocodile's mouth, and the crocodile does not close its mouth to eat the birds. It is beneficial for both animals. But do you think this relationship is required for surviving? Is it Mutualism? I wonder…
Giovana:	… one helps the other, isn't?
Teacher:	… He can only survive if he is together with the other?
some students:	NO
Ana:	I think they need to [be with each other to survive].
Paula:	It is like the anu [*Crotophaga ani,* a South American bird] picking ticks.

In the transcript, the lesson progresses with the teacher posing a series of questions to students to help them to understand that the example they chose could not be considered mutualism. He does not confront students directly at any moment in the lesson – an approach that promotes a more dialogical learning (e.g., Cazden, 2001).

PBTs were asked to examine transcripts with four aspects in mind: (i) Characterize briefly the lesson as a whole (what topic is addressed?, what resources the teacher uses?, describe the teacher and the students); (ii) Describe how the teacher interacts with students when addressing scientific concepts; (iii) Describe how the teacher deals with students comments/answers; and (iv) Describe the comments/answers students make. PBTs have to give examples of parts of the transcript to illustrate their responses. After conducting and recording their "analysis" of the transcript, the whole class share their "results". At this point, again, different perspectives emerge. In relation to the lesson described above, for instance, ideas from two groups differed significantly:

> … we see that the teacher ends up bringing new doubts about the topic, that he himself does not demonstrated confidence when he answered students' questions." … the teacher seamed to be disoriented often saying "I think"

> The teacher is very dialogic, posing questions and asking for examples to construct the knowledge with the students. The students participate actively and question, bringing new issues to the classroom."… At every moment the teacher tries to start from examples to argue with students.

Thus, there are always criticism or praising to teachers' work: "she/he knows how to listen", "she/he doesn't have control over students", "it is confusing. She/he comes and goes, and doesn't get anywhere", "she/he knows the content and introduces it dialoguing with students".

The instructor's role involves helping PBTs to develop criteria to evaluate the quality of a lesson (or parts of it) based on the nature of classroom interaction. PBTs have to learn to be attentive to how teachers use language and to consequences of his/her discourse, based on students' actions and reactions. PBTs have to use transcripts to support their assertions about aspects of teaching that take place in this classroom. For instance, when working with the transcript mentioned above, if one argues that the teacher does not know the content, a careful analysis of the transcript will show that one of the consequences of teacher asking questions and not demonstrating certainty was that students were able to participate more, to express and to contrast their perspectives in light of evidence that was available. Moreover, as PBTs examine questions that the teacher poses, with help from the instructor, they are able to identify a conceptual structure that organizes them (i.e., framing phenomena in certain ways). In the lesson described, for instance, the concept of mutualism is emphasized through questions like "is the relationship required for the organisms to live?" and the very structure of the discussion.[7] Finally, based on students' responses, PBTs will be able to find evidence of learning about ecological relationships as well as of participation in scientific practices (e.g., talking about evidence). In sum, by the end of the lesson, PBTs start to perceive differences in interactions teachers and students engage in, with different purposes, for instance: (i) some involve learning about students' knowledge and establishing relationships with biological knowledge; and (ii) others involve introducing biological knowledge.

In the following lessons, the ways of using language to introduce subject matter knowledge are further explored for introducing academic discussions about classroom discourse (with readings like Driver et al., 1989). PBTs will be also introduced to Mortimer and Scott's (2003) work, so they can develop ways of systematically analysing classroom interactions and, in the future, reflect about – and reshape – the ways he/she interacts with his/her own students as a teacher.

ASSESSMENT TO EVALUATE AND PROMOTE SCIENCE LEARNING

Teaching Science Portfolio

One of the assessments that is particularly important in the BioEd Methods I is the Portfolio. It is elaborated across the two Methods courses offered at the CEd and the three Practicum courses (Table 2). PBTs elaborate a first version in the

6th/7th semester of the course including artifacts and reflections related do the first Practicum course and to the first Methods course. In the following semesters, PBTs incorporate revisions of their reflections considering what they experienced and learned in each BioEd Methods and Practicum courses.

The implementation of this assessment in our courses was guided by Dana and Tippins's (1998) perspective on portfolio's potential to integrate knowledge from different contexts over time, and to promote reflection. For these authors, the science teaching portfolio is "a researched presentation of the coached or mentored accomplishments of a teacher of science documented with teacher and student work and substantiated by reflective writing" (p. 723).

Informed by this model, and by a structure developed at Penn State University (PSU) in the early 2000s (Friedrichsen et al., 2003), the Portfolio at UFMG is divided in two sections: (i) Reflection and (ii) Artifact Collection. In the Reflection Section PBTs have to elaborate statements that reflect their view on three issues: (i) to be a teacher; (ii) what characterizes science and biological sciences; and (iii) teaching and learning science and/or biology. PBTs have to support/illustrate their statement with an example of an artifact from the Artifact Collection Section, explaining the relationships and why these artifacts were selected. The Artifact Collection includes PBTs artifacts produced during BioEd Methods (e.g., Investigation of students' alternative conceptions, planning of an innovative unit, readings, exam, participation in online forums) and during Practicum courses (e.g., PBTs' journals, lesson plans, worksheets used at school, artifacts from K-12 students). The Portfolio is usually presented as a physical binder, but students can also present it in electronic format.

Every semester, PBTs incorporate new artifacts and make revisions of their reflections, considering what they experienced and learned in the Practicum and/or Methods course at CEd in that semester. PBTs also include a few paragraphs reflecting explicitly about changes that occurred from one semester to another. The professor that is teaching the Method course/Practicum is responsible for evaluating the quality of the portfolio, considering if PBTs: (i) presented ideas with appropriate depth; (ii) elaborated text that is clear and has internal coherence; (iii) included artifacts related to the course; (iv) established relationships between artifacts and assertions; (v) presented ideas that are coherent with current ideas in the field of science education that were discussed in the course; and (vi) elaborated a short essay discussing changes/trends in ideas up to that point in the program.

We believe that this assignment has supported PBTs in constructing relationships between knowledge and experiences from different courses and from different settings. Moreover, there is evidence that this assessment has a significant role in helping PBTs in constructing more robust and research-based views of science teaching and learning. However, we face various challenges, considering that adopting this type of assessment involves a change in school/classroom culture. Gitomer and Duschl (1995), for instance, talk about a Portfolio Culture and how it requires changes in: (i) conceptions of science, science thinking, and goals for science education; (ii) conceptions of student learning and appropriate instruction; and (iii) role and practice of assessment. These changes should not be seen as a prerequisite for adopting Portfolio assessment, but as part of the process and consequences of adopting this approach. In other words, it is inevitable that, during the courses, elaborating the texts for the Portfolio will bring conflicts to students. One of the major challenges involves developing more authorship in written texts. For PBTs, the very notion that they have to elaborate a statement that reflects their beliefs is something considerably new because they are usually asked to demonstrate understanding by reproducing textbook or lectures' ideas. Thus, they struggle to identify important ideas and to openly talk about them – and, actually developing them. Second, PBTs often have difficult in relating their statements to what they experienced or to the readings in the course. In other words, it is hard for them to establish relationships between their ideas and artifacts, and making explicit what are the relationships that they have established. This indicates that prior to these courses, PBTs do not have enough opportunities to engage in argumentative practices that could help them to understand aspects like the role of evidence in knowledge construction, and developing abilities to justify their ideas (Zohar, 2007). Finally, in the Portfolio's first version, PBTs tend not to integrate experiences at school and academic knowledge (e.g., specific readings). As they progress in the program, they establish more connections.

Report on the Investigation of Students' Conceptions

Another important assessment is the Report on the Investigation of Students' Conceptions. The main goals of this task is for PBTs to learn about students' conceptions related to a Biology topic, as well as for them to develop strategies to assess students understandings. PBTs work in groups to plan and develop an activity/lesson. They are explicitly oriented *not* to try to "teach" students anything, but mainly to make sure PBTs themselves learn something about students' thinking. This report actually derives from a series of activities developed in various lessons, addressing multiple aspects of learning to teach biology.

After participating in the lesson about students' conceptions described in this chapter's section on classroom practice, PBTs are asked to choose a biology concept/topic to investigate in groups of 3–2. The motivation for choosing a topic could vary. PBTs worked with concepts that: (i) will be addressed in the classroom after PBTs develop the activity at school, (ii) was related to what PBTs study in biological research labs where they work in internships; (iii) was considered a topic frequently addressed in science curricula; (iv) was considered particularly difficult to teach (e.g., it was too "abstract", centred on information). PBTs tends to chose concepts related to the following topics: (i) genetics and heredity; (ii) human/animal physiology; (iii) plant anatomy and physiology; (iv) classification of living beings; (v) microbiology; (vi) evolution; (vii) ecology.

Once PBTs choose their topics, they read papers that report on students' alternative conceptions about it, and elaborate a summary of results from these previous studies. This preliminary review of the literature has an important role in helping PBTs to move from an anecdotal knowledge about alternative conceptions to a more robust and more scientific knowledge about them.

In the following lesson, in class, PBTs get together in their groups, and use the examples of students' ideas they found in the literature to better understand epistemological obstacles proposed by Bachelard (e.g., Mortimer, 1998). This activity supports PSTs in learning about the diversity and commonalities among alternative conceptions in different topics. These examples evidence how alternative understandings have an underlying rationale, that often conflict with scientific reasoning, and with conceptual structure of biological sciences, (Mayr, 1982) but still is a rationale (Bricker & Bell, 2008). For instance, we present examples that reflect the prevalence of a finalist approach to natural phenomena (e.g., plants grow in certain direction to get more light; photosynthesis occurs to purify the air; living beings evolve to survive, etc.), and contrast this perspective with a scientific one that focuses on mechanisms that cause the phenomena (e.g., living beings have characteristics that originate from a stochastic process, and under different selective pressure some survive and others do not).

In the other two lessons related to this assessment, PBTs will focus on issues of *how* to assess students' alternative conceptions. The activities involve promoting a contact with different approaches for eliciting students' ideas, and engaging PBTs in reflection about the implications of choosing a certain procedure. In class, PBTs: (i) contrast questions form different questionnaires on conceptions about evolution and natural selection, and (ii) experience, as students, the use of practical activities for eliciting conceptions.

During 3–4 weeks PBTs plan activities to develop at school. The instructor gives feedback on their proposal. At school, they record (in video, audio or in writing) aspects of the development of the activity (e.g., students answers, predictions, reactions). We encourage PBTs to adopt different approaches to assess students' conceptions and to combine them as much as possible. Table 4 presents examples.

After conducting the activities, PBTs elaborate a report including: (i) short introduction explaining the goals and the relevance of the investigation; (ii) description of students and of school; (iii) description of how the activity was developed; (iv) characterization of students' conceptions, with examples of student artifacts (e.g., drawings, writing); (v) contrast with conceptions from literature, with possible explanations for their occurrence. PBTs are graded considering not only the quality of the report, but also their participation in planning and developing the activity.

This assessment has contributed to PBTs' learning in various aspects. First, they become more aware of the diversity and complexity of students' thinking considering multiple elements of the subject matter knowledge:

Table 4. Examples of different approaches and activities PBTs used to assess students' conceptions

Approach	*Topic*	*Grade*	*Example(s)*
Practical Activities	Evolution and Plant Biology		In groups of 3, students observe and draw leafs from 3 different plants. Then, they discuss why they think they were different.
Practical Activities involving students as source for data	Animal Physiology	6th	"The temperature of the environment today is 25^{o}C, what do you think would be our body temperature?" Take measurements. "Why do you think it is higher than room temperature?"
	Nervous System	7th	Students stay close to a wall and try to raise one of their arms for about a minute. After moving away from the wall the arm raises "by it self". Students' try to explain what happened, and talk about how they think we control our body movements, what are the organs that do that, where they are.
Pictures	Plant reproduction	6th	Establish relationships between pictures of plants, fruits and animals, and explain these relationships.
	Evolution	9th	Write down adaptations of the organism (e.g. rattle snake, chameleon) and then, discuss as a whole class, what are these adaptations and their origin.
Cards	Micro-organisms	7th	Students have to group cards (including examples of organisms and diseases, and other words like dangerous, alive, beneficial) into two categories (are/are not microorganisms). (Inspired by Cobern, 2000, World View cards)
Questions situated in "broader" contexts	Plant physiology	11th	"It is very hot outside! At this time of the year, the gardener waters the plant every day, but he has been sick for two days. Apparently, the plants did not change. How do they resist?"
Questions related to scientific knowledge production	Genetics	8th	"What do you think motivated Brazilian scientists to create a cow clone? What could be reasons for conducting this type of experiment?"
	Insects	6th	"If you were a scientist what insects would you like to investigate? What would you do to learn more about these animals?"

> Frequently, students may understand a concept, but do not know how to use it to understand concrete situations. [plant anatomy and evolution 10th grade]

> Most students understand that there is a pause between heartbeats. However, when questioned about why there is a certain expected frequency, students associated the working of a heart to the process of "milking a cow". They do not talk about valves opening or closing. [cardiovascular system – 8th grade]

> Considering how students related pictures of animals to pictures of plants/fruits/flowers, we concluded that they know little about the importance of pollination and seed dispersion. Their conceptions are more related to predation and herbivory. [plant reproduction 7th grade]

As PBTs become aware of nuances in students' conceptions, some problematize aspects of K-12 science curricula. For instance, Francis, investigated 10th graders conceptions about plants responses to environmental conditions. Considering his knowledge and experience in a research lab on Plant Phisiology, he concluded that:

> Students correctly associated adaptation with germination, but their analyses of what was happening was inaccurate. All the plants are adapted to the environment, but they have different strategies. Students seem to have an idea that, if a seed did not germinate immediately, it will not germinate anymore. This idea reflects the notion that what is good for the plant is good for germination. Usually, in K-12 education there is little opportunity to study seeds characteristics. This topic is addressed only in the context of "plant reproduction", not when learning ecology or evolution.

Moreover, PBTs were able to associate the complexity of students' conceptions with elements of Bachelard's epistemological obtacles:

> We were able to observe some "trends in thinking" mentioned in Santos (1991). For instance, one student stated that "there is no problem if cousins have children because my cousins had a child who had no problem". This statement reflects a way of thinking in which "more salient aspects of a concrete situation prevail" (Santos, 1991). Moreover, students' conceptions reflect a tendency to "move easily from one meaning to another without realizing it, associating or differentiating concepts based solely on linguistic basis". That was the case when students used similar explanations – all based on blood type "compatibility" – to three different situations (i.e., blood transfusion, paternity testing, reproduction between cousins).

Furthermore, PBTs are able to identify the potential of students' prior knowledge to biology teaching:

> A student who was born and raised in the countryside remembered that when he was walking at night in a path without lights, frequently, the darkness was intense and he relied on his memory to know where to go. He compared his

> experience with what happens with people with disability that use their sticks, and he explained how they develop skills to compensate for the lack of vision. During all activities we perceived that students already had some knowledge, directly connected to past experiences. Thus, these experiences can become a resource for teaching. [senses, 7th grade, adult learners]

Finally, depending on the procedures adopted in their investigation, some PBTs learned about students' conceptions related to processes of knowledge production and scientific practices:

> when students had to imagine they were scientists, they demonstrated they had interest in researching about animals that they knew little about. However, their investigation would be based on consulting the Internet to find information about the insects. None of them mentioned direct observation as a source for learning more about animals. [insects – 7th grade]

In sum, this assessment creates opportunities for PBTs for developing more complex understandings of alternative conceptions and how to develop practices to learn about their own students.

CONCLUSION: DEEPENING RELATIONSHIPS BETWEEN THEORY AND PRACTICE

Establishing relationships between theory and practice has oriented our Program. The Methods course described in this chapter was designed mainly to create opportunities for PBTs to learn about key ideas in the field of science education. Establishing a dialogue between teaching practice and academic knowledge/practices can be challenging. First, it is essential to provide a space for PBTs to express their ideas, position themselves, share their experiences, and their ways of doing things. Otherwise, issues of identity become a significant obstacle to learning to teach. Second, contexts related to teaching practice have to be present when addressing academic knowledge/practices. In BioEd Methods I we aim to engage PBTs in using both what has been produced in the academic field of science education (e.g., the role of language, students' knowledge) and the practices that are adopted in the field (e.g., making explicit our thinking, reflecting about our actions and positions, examining what supports our thinking) to account for what happens and what can be done in school settings. We have evidence that PBTs made progress in participating in argumentation about science teaching as well as in reflecting about their views of learning and their experiences at school.

However, we believe this progress can be even more significant if we create more contexts for meaningful interaction between PBTs, and emphasize more critical thinking development in the course. Aspects like context, agency and power relations, should receive more attention when addressing classroom discourse and science learning (e.g., Bloome & Clark, 2006; Brown et al., 2005). Moreover, PBTs need to engage in critical thinking about their own practice. We need to develop strategies to problematize their own practice and its relationship with theory in the context of Methods courses. For instance, there could be more tasks that require PBTs to bring artefacts from Practicum courses into Methods courses. Moreover, PBTs need to engage more in activities involving sharing, taking positions and collaborating with each other in problem solving. In this respect, activities involving relationships between science, technology and society can foster a critical view of science, as well as PBTs participation in critical discussions.

Considering the current educational scenario in Brazil, it is fundamental that science teachers have robust knowledge for teaching, including being able to participate in public debate and to argue for the importance of science education for our society. We hope we can contribute for their development in this direction.

NOTES

1. In Brazil, students at public schools take courses without having to pay for tuition.
2. Teacher education guidelines are established by the Brazilian council of education, that is composed by with representatives of different sectors of society. By the end of 2015, new guidelines for Teacher Education were established, but, evidently, they were not implemented yet at the universities.
3. Currently, the team is composed by the authors of this chapter, as well as Dr. Julio Emílio Diniz Pereira, and Dr. Marina Assis Fonseca.
4. This investigation is described later in the chapter as an assessment.
5. In Brazil we still have a significant number of adults that have not concluded k-12 education. Thus, there are various schools that have classrooms for 1–12 grades for adult learners.
6. They also have contact with transcripts of interactions in lessons about: (i) digestive system in a 7th grade classroom; (ii) mixture and substance in adult education; (iii) pressure in 8th grade; (iv) living and nonliving being in 2nd grade; (v) what is science in 1st grade. The range of lessons has broadened, considering that we use transcripts mainly from research that take place in our Grad School Program.
7. For more detailed analyses see Souto and Munford (2014).

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8. CHEMISTRY TEACHING METHOD COURSE FOR SECONDARY SCIENCE TEACHER TRAINING

An Example from Turkey

INTRODUCTION

In Turkey, Colleges of Education train pre-service teachers (PSTs) and give a certificate to serve as a teacher in either public or private schools. In the Turkish system, teacher education has been divided into three departments, namely pre-school, elementary, and secondary teacher education. The number of semesters and the courses/credits taken may change depending on the department; in this chapter we focus only on Secondary Science Teacher Preparation Programs (SSTPP). Additionally, SSTPP is itself separated into the fields of physics, chemistry, and biology. All sub-divisions provide their own teaching methods course; it is a great advantage for teacher educators to teach a methods course for the specific field in which they have strong subject matter knowledge. It is also an advantage for PSTs because they take the teaching method course from a teacher educator who is an expert in that specific discipline. PSTs graduating from SSTPP also teach strictly within their science specialism. In this chapter, due to the authors' experience and background in chemistry teacher education, we focus on the details of the chemistry teacher education division, which is fairly similar to the biology and physics teacher education divisions. The methods course in question is a five-credit course and offered four class hours per week.

In this context we, as secondary science teacher educators, prepare PSTs for teaching chemistry to high school students (i.e., grades 9–12). The program is 5-year undergraduate program leading to a teaching certificate that has 10 semesters (i.e., a semester includes about 12–14 weeks). To graduate from one of the programs, PSTs need to take 30 credits per semester, which means PSTs are required to take 300 credits (i.e., 10 x 30 = 300 credits) in total to graduate. Credits are calculated in light of the European Credit Transfer and Accumulation System (ECTS). The National Council of Education (NCE, 2016) determines the major required courses and their credits. However, elective courses are determined by the program. PSTs take subject matter courses (e.g., General Chemistry, Organic Chemistry, and Physical Chemistry) and pedagogical courses (e.g., Introduction to Educational Science, Educational Psychology, and Classroom Management) in the first seven semesters. Then, the domain-specific Chemistry Teaching Method Course I and II (both courses

A. J. Sickel & S. B. Witzig (Eds.), Designing and Teaching the Secondary Science Methods Course, 129–148.

are mandatory) are offered in the 8th and 9th semesters. In the 9th semester, PSTs take a "Teaching Experience" course through which they observe mentor teachers' practice, learners, and administrative work. In the final semester, PSTs take a "Teaching Practice" course in which they plan and practice in high schools under the guidance of a licensed mentor teacher. The teaching practice course is about a 12-week course through which pre-service teachers spend about four hours per week in cooperating high schools for both observation and practice teaching.

In Turkey, we have only two pathways to earn a certificate to teach in schools. The certification institutions, which are Colleges of Education, are undergraduate institutions. The programs award bachelor's degrees in chemistry, physics, and biology teaching at the secondary level (i.e., grades 9 to 12), about which the details were presented above. Another pathway to licensure is admitting to the alternative certification programs with a bachelor's degree in the science discipline (e.g., chemistry, biology, etc.). The candidates preferring the second pathway also take pedagogy courses (e.g., classroom management) and discipline-specific teaching methods course (e.g., Chemistry Teaching Method Course) that are specifically related to the domain-specific instructional qualifications. Different than the other program, alternative ones offer only one domain-specific Chemistry Teaching Method Course in the second semester. Teacher candidates applying for the alternative program take an accelerated version of the course. In other words, candidates in this program miss out on some parts of Chemistry Teaching Methods I and II, and the depth at which we use to Pedagogical Content Knowledge (PCK) and Content Representations (CoRes) to inform their chemistry-specific practice. The alternative certification program is a 2-semester program added on to their existing science content bachelor's program (i.e., 25 credits in total) that has a teaching practicum in cooperating high schools in the second semester. The discipline-specific teaching methods course is pretty similar to the ones offered in the first certification programs already described (the 5-year, 10 semester program). However, candidates take two discipline-specific teaching methods courses in the undergraduate program (e.g., Chemistry Teaching Method I & II) whereas candidates in the alternative certification programs take only one methods course.

In Turkey, the Fundamental Law of Education has stated that the National Ministry of Education (NME) determines the qualifications that teachers are required to have (NME, 2008). Our institutions, which are Yüzüncü Yıl University in Van city and Bülent Ecevit University in Ereğli town, are in the very east and northwest parts of Turkey, respectively. Our contexts are pretty similar to other contexts in our country due to the fact that the standards and accreditation rules are applied to all of the teacher education programs in the country. The qualifications that teachers are required to have are classified into three main categories, namely liberal education, pedagogy, and domain-specific instructional qualities. Although the contexts are very similar to each other, in practice some differences may be observed, especially in planning and practicing science teaching methods courses. We, as chemistry teacher educators, have had interest in PCK, that is a professional knowledge base for teaching (Abell, 2007). Therefore, we are able to highly integrate all standards in light of the PCK framework by NCE and NME.

Through the pre-service teacher education program, PSTs take different courses from those three categories. Science Teaching Method Course I and II are the ones specifically related to the domain-specific instructional qualifications. To form the standards for teacher education, a commission under NME determined six general qualification standards related to knowledge about learner, teaching and learning, assessment and evaluation of students' learning, curriculum, professional values, and the relationship among parents, school, and society. There are many sub-standards and performance criteria under those six standards, but due to page limitations we will not mention all the details. Science Teaching Method Course I and II are highly related to the six general qualification standards determined by NME. Method Course I is devoted to the introduction of PCK (Abell, 2007), the nature of science (NOS) (Lederman, 2007), and topic-specific instructional strategies (e.g., analogies and animations). In Method Course II, we pay specific attention to developing PSTs' knowledge about students' difficulties in learning chemistry concepts, their alternative conceptions, use of high school chemistry curricula, how to apply instructional strategies for effective teaching of chemistry topics, and how to assess learners' development. Finally, after graduation, teacher candidates have to take an exam to be a teacher in state schools. The program does not explicitly prepare the pre-service teachers for the exam, however, most of the courses (e.g., content courses, classroom management) provided in the program support candidates' preparation for the exam. Additionally, if candidates pass the exam and become a teacher nearby, we encourage them to apply to our graduate program. In this exam, questions asked are from the three categories (i.e., liberal education, pedagogy, and domain specific instructional qualities) determined by the NME. In this chapter, we focus only on Science Method Course II.

PLANNING: DISCUSSION OF COURSE DESIGN

The Major outcomes and Topics for the Course

In the science method course II, we aim to develop PSTs' PCK for teaching chemistry to high school students. The PCK framework has a vital role in designing teacher education programs. For instance, Abell, Appleton, and Hanuscin (2010) used it for designing elementary science teaching methods courses and Davis and Krajcik (2005) used it for designing educative curriculum materials. Furthermore, Sandra K. Abell stated that she used the framework for designing a teacher education program, an alternative certification program, and for writing the handbook chapter focusing on pre and in-service science teacher education (Abell, 2008). In addition to research, standards in Turkey also mentioned PCK and its components (NME, 2011). In light of those, the PCK framework shaped the design of our course.

Before this course, PSTs take Science Teaching Method Course I, during which we talk about learning theories, teachers' professional knowledge base (i.e., PCK), subject matter knowledge (i.e., chemistry topics), topic-specific instructional strategies (e.g., animations, simulations, and predict-observe-explain), and meaningful learning during which we focused on the role of both cognitive conflict (Chan, Burtis, & Bereiter, 1997) and conceptual change (Posner, Strike, Hewson, & Gertzog, 1982). In the method course II, throughout the semester we focus on each PCK component (i.e., orientation to chemistry teaching, knowledge of learner, curriculum, instructional strategies, and assessment) and try to enrich PSTs' PCK for teaching chemistry. To be more specific, we used Magnusson, Krajcik, and Borko's (1999) PCK model in designing the course. The semester starts with uncovering PSTs' beliefs about the purposes of teaching science/chemistry. Then, we talk about the difficulties that the high school students may have in learning chemistry topics (e.g., acid strength and mole concept) and alternative conceptions that they may have. Later, we examine the high school chemistry curricula regarding objectives, curricular materials, and horizontal and vertical relations of the topics. After introduction of the curriculum and how to use it, we focus on science-specific instructional strategies (e.g., learning cycle, inquiry, drama, role playing, and argumentation). To increase the probability of PSTs' use of the strategies in their future teaching, we teach all of the strategies in a specific chemistry topic. For instance, we applied the learning cycle to the context of rate of reaction topic to teach rate, instant rate, and average rate concepts. In this way, we aim to make those strategies chemistry-specific. Moreover, to teach how to use animations and simulations in teaching chemistry topics (e.g., Particulate nature of matter), we purposefully select some good and problematic animations and simulations. We discussed how to use them effectively and how to use them to support students' understanding of chemistry. Finally, we focus on how to assess learners' development and in which domains we can assess (e.g., affective, psycho-motor, and cognitive). Similar to other components, we specifically talk about the use of different assessment strategies (e.g., concept map, rubrics, portfolio) in assessing students' understanding of chemistry topics (e.g., chemical reactions, chemical equilibrium).

In addition to developing PSTs' understanding about PCK and its components, we also pay specific attention to supporting PSTs' meaningful enactment of PCK components in harmony. At the end of the semester, after introducing the PCK components, we introduce a specific tool, the CoRe, (see Table 2) developed by Loughran, Mulhall, and Berry (2004). After group work of preparing their CoRes, PSTs are required to plan and enact microteachings on a specific topic from the high school chemistry curricula. With the CoRe assignment and microteaching, we intend to make PSTs use the PCK that they developed throughout the semester. To plan and enact a lesson, PSTs need to focus on objectives in the curricula, learners' possible difficulties, instructional strategies used for effective teaching, and how to assess learners' understanding. In Turkey, in-service chemistry teachers are not required to prepare a written lesson plan using a specific template. However, they are required to reach objectives in the national curriculum through the use of teaching and assessment activities. To support PSTs to design effective teaching, we have utilized the CoRe since its introduction by Loughran and his colleagues (Loughran et al., 2004). When we introduce the CoRe to PSTs, we compare and contrast the CoRe with a common lesson plan template that we used previously by emphasizing the strengths of the CoRe for both development of teachers' knowledge and skills for teaching chemistry and students' meaningful learning. To that end, in this course we aim at developing both knowledge and skills for teaching chemistry.

Factors Influencing the Selection of Outcomes and Topics

The schedule of the course is presented in Table 1. In the process of preparing the syllabus, we were influenced by the PCK framework (Abell et al., 2010; Aydin et al., 2013; Loughran, Mulhall, & Berry, 2008), which has been widely used by teacher educators. PCK and its components provide specific areas of focus (e.g., curricula, learner, and assessment). Furthermore, research has shown that PCK is useful for examining teachers' learning and development (Friedrichsen, 2008). We, as teacher educators, have conducted research with pre- and in-service teachers by using the PCK framework, and found that PCK offers a road map for both teacher education and analyzing teachers' professional knowledge base. Moreover, we utilized CoRes as a lesson plan format and realized that it helps PSTs think holistically. Before CoRes, we used a classic lesson plan format. We experienced inconsistencies in the plans prepared by the PSTs. Unlike the classic lesson plan format, the CoRe's matrix helps PSTs to see the connections among objectives, learners' difficulties, instructional strategies, and assessment.

In addition to the PCK framework, our research, experience, and the qualifications determined by NME (2011) influenced the topics included in the course. As mentioned above, teachers have to be qualified regarding knowledge about learner, teaching and learning, assessment and evaluation of students' learning, and the use of curriculum. The PCK framework and national standards are also aligned with this model, which made the planning easy for us.

The Reason for the Sequence of the Topics

After Method Course I, which introduces PCK as the knowledge base for teaching and its components, NOS as defined by literature that is relevant and accessible to K-12 students (e.g., Abd-El-Khalick, 2012; NGSS Lead States, 2013; Erduran & Dagher, 2014; Lederman et al., 2014), and topic-specific instructional strategies (e.g., analogies, activities, demonstrations, and Predict-Observe-Explain), we start the semester by digging into PSTs' orientations toward science and chemistry teaching. This component of PCK has an overarching role over other components (Magnusson et al., 1999). It is also a necessity to start with beliefs about teaching because beliefs

Table 1. Methods of chemistry teaching II course schedule

Sessions	*Topic*	*Readings/Assignments*
	First Meeting	Introduction to the course
Week 1	Orientation Towards Teaching	Beliefs about the purposes of science teaching Beliefs about science teaching and learning Beliefs about nature of science Central and peripheral goals Translation of orientation to teaching
		Preparation of Pre-PCK map (Assignment)
Week 2	Knowledge of Learner	Learners' prior knowledge Learners' difficulties in learning the particular topic Learners' alternative conceptions regarding chemistry topics
		Project on learners' alternative conceptions about a particular topic
Week 3	Knowledge of Curriculum	High School Chemistry Curriculum Horizontal and vertical relations among topics Curricular materials for teaching chemistry and nature of science
Week 4	Subject Specific Instructional Strategies	Learning Cycle and Inquiry
Week 5	Subject Specific Instructional Strategies	Drama & Role Playing
Week 6	Subject Specific Instructional Strategies	Argumentation
Week 7	Subject Specific Instructional Strategies	Cooperative Learning
Week 8	Subject Specific Instructional Strategies	Explicit and implicit approaches for teaching NOS
Week 9	Knowledge of Assessment	Dimensions to assess Methods of assessment
Week 10	Lesson planning	Introduction of the CoRe
Week 11	Lesson planning	Group work on the CoRe
Week 12	Microteachings	Reflection on each other's teaching practice and submitting "Evaluation of Microteaching"
Week 13	Microteachings	Reflection on each other's teaching practice and submitting "Evaluation of Microteaching"
Week 14	Microteachings	Reflection on each other's teaching practice and submitting "Evaluation of Microteaching"
		Preparation of Post-PCK map (Assignment)

shape teachers' planning and teaching (Pajares, 1992). Through discussion about why we teach science/chemistry and the goals of science/chemistry education, PSTs realize that national goals should be addressed through teachers' practices in classrooms. In Turkey, the major national goal of science education is to train scientifically literate citizens who have adequate knowledge about science and NOS to understand the scientific events, phenomena and the news, solve daily-life problems by the use of scientific knowledge, and understand nature of scientific inquiry (NME, 2013). Therefore, we focused on the national goals of science education regarding scientific literacy and talk about why it is important to have scientifically literate citizens. This part is vital because pre-service teachers should develop orientations parallel to the national goals. Second, we focus on high school students' prior knowledge from elementary school and/or daily life. We also talk about the possible difficulties in learning chemistry topics (e.g., acid-base strength and electrochemistry). Additionally, alternative conceptions that learners possess and their possible explanations are a main focus of the second week. Because the PSTs learned about the possible difficulties and alternative conceptions that students may have in Chemistry Teaching Method Course I in the previous semester, in the second method course we basically help PSTs remember the possible reasons for the difficulties and/or alternative conceptions. Then we examine high school curriculum, focusing on objectives, the horizontal and vertical links among topics, and how to use the materials offered to plan a lesson. After that, we focus on chemistry-specific instructional strategies and how to use them. We introduce the strategies by modeling them for teaching a specific chemistry topic (a detailed example will be given below, regarding the argumentation strategy for teaching chemical reactions). While we model and introduce the instructional strategies, we also connect what PSTs learned about meaningful learning (i.e., with a focus on cognitive conflict [Chan et al., 1997] and conceptual change [Posner et al., 1982] in Method Course I) with the strategies they are learning to use. Finally, we mention assessment strategies and the domains for assessment. The sequence is quite useful for developing PCK and preparing PSTs for planning a lesson. They need to be aware of their beliefs about teaching, focus on objectives and learners' levels, decide which strategy to use, and assess learners' development. Additionally, the sequence we follow is aligned with the questions in the rows of the CoRe, which is a signature assessment in our course. PSTs often see a large gap between the theories they learned through their program and the reality of teaching in practice (Holt-Reynolds, 2000). Using CoRe as a lesson planning tool and for assessment purposes helps us to see to what degree we, as teacher educators, are able to close this gap. Additionally, teachers' pedagogical professional knowledge base is tacit in nature (Loughran et al., 2004). The CoRe structure is helpful in explicating teachers' knowledge bases, including their PCK, both at the understanding and enactment level. Moreover, a lack of shared language for PSTs' thinking about teaching (Carter, 1993) prevents many method courses from reaching their intended objective: preparing PSTs who are able to design effective instruction that cultivates students' meaningful learning and who have a strong professional knowledge base, which includes PCK.

After completing the development of PSTs' understanding of PCK, it is necessary to spend time and energy specifically on the enactment part of PCK development. PSTs have reflected that the CoRe preparation and microteachings support their use of PCK components because they require the use of all parts of PCK in harmony for effective teaching.

The Development of the Assessments

In this course, we use a portfolio (i.e., a physical binder) to assess the development of PSTs' professional knowledge and skills for teaching chemistry. PSTs put all course assignments, projects, reflection papers, and CoRes into their portfolio. We pay specific attention to PSTs' professional development in two levels: understanding and enactment. Park and Oliver (2008) express that those two levels are distinct. For understanding, PSTs are required to write reflection journals regarding the topics assigned each week. They are required to reflect on what they learn and how to apply that knowledge in class. In addition to that we ask them to prepare a PCK concept map, both at the beginning and at the end of the semester. Because they are familiar with the PCK concept from Methods Course I, they are able to conceptualize the construct. We have experienced that introducing PCK and using the construct through the semester helps them to mentally structure the knowledge components necessary for effective teaching. The pre– and post–PCK concept maps are helpful for us to see the PSTs' development. The work of Lee and Luft (2008) inspired us to include this assessment in the course. They stated that PCK conceptualization is helpful in understanding teachers' learning over time. We also assign a project through which PSTs study high school students' alternative conceptions. They are encouraged to conduct an interview with high school students or examine chemistry textbooks in search of alternative conceptions they may create.

To foster the enactment level of PCK, we assess development by observing microteachings and analyzing the CoRes the PSTs prepared. Microteachings are assessed formally by the use of an observation form (i.e., including criteria about whether PSTs use instructional strategies effectively and focus on learners' alternative conceptions). PSTs receive a grade on microteaching, which forms about 10 to 15 % of PSTs' grade of the practice teaching course. Regarding the CoRe use, Nilsson and Loughran (2012) stated that CoRe use "acts as a trigger to encourage student teachers to begin to embrace the notion of PCK in their own practice" (p. 719). We also have them observe their peers' performance during microteaching and reflect on those, which is highly useful because PSTs generally make similar mistakes in planning and teaching. In this way, they also have a chance to realize the weak parts and inconsistencies in their own instructional strategies and assessments. Additionally, in the CoRe preparation assignment, the PSTs need to work in groups to foster an environment where they will learn from each other. Each PST has both well developed and less developed PCK components. Hence, we expect them to support each other (Loughran, Berry, & Mulhall, 2012).

CLASSROOM PRACTICE

Learning to Use Argumentation as a Teaching Strategy

We believe that argumentation, as a teaching strategy, is critical to our course for three reasons. First, argumentation is a scientific practice that scientists engage in (NGSS Lead States, 2013), and therefore students should use it in order to better understand NOS (e.g., Yerrick, 2000). Science is not only a collection of facts; it involves producing models, theories, and explanations about how the universe works. During this production, scientists are involved in argumentation by experiencing conflicts and disputes. To provide a more coherent picture of NOS, students should experience this argumentation process. Second, argumentation supports the use and development of students' scientific reasoning and critical thing skills (Erduran & Jiménez-Alexander, 2008), which are important for scientific literacy. Third, argumentation as a teaching strategy aligns with inquiry-based learning (Sampson, Grooms, & Walker, 2009) and provides opportunities for students to experience scientific practices (e.g., asking questions, making observations, and experimenting). When integrated with argumentation, inquiry-based learning offers a richer context for students to experience more authentic scientific practices.

We structured the course considering two main learning theories: social cognitive theory (SCT) (Bandura, 1986) and constructivism, including personal (Piaget, 1972) and social constructivism (Vygotsky, 1978). According to SCT, individuals learn through the observation of models and the effects of their actions. Therefore, two of the fundamental ideas of our course find their theoretical roots in SCT—observational learning and self-efficacy. Observational learning refers to the idea that people can learn by observing and copying others (Bandura, 1986). Therefore, we model argumentation as a teaching strategy in which we act as teacher and PSTs act as a high school students. However, modeling alone is not enough to help PSTs learn argumentation as a teaching strategy because PSTs tend to think from the perspective of a learner unless they are asked to do otherwise (i.e., think as a teacher) (Demirdöğen, Hanuscin, Uzuntiryaki-Kondakçı, & Köseoğlu, 2016). Also, effective observation of skilled practice can be difficult as skilled practice is often subtle. Therefore, we ask them to think from the perspective of both teacher and learner during modeling. Moreover, teachers' professional knowledge base is tacit in nature (Loughran et al., 2004) and more explicit-reflective experiences are necessary to stimulate their PCK development (Aydın et al., 2013). We explicitly ask PSTs to reflect on their observations and experiences, considering questions given before modeling the strategy such as; What are the basic components of the argument-driven inquiry instructional model?; Which difficulties may you encounter while using this strategy?; Which chemistry topics are more suitable to teach with argumentation?; Which component of PCK develops as a result of this argumentation modeling experience?; How does argumentation as a teaching strategy align with your science teaching orientation?; What is the teacher's thinking when planning and implementing argumentation for teaching this topic?; What are the ways to increase effectiveness of argumentation for different types of students?; These questions help PSTs find out about skilled teachers' thinking and stimulate PSTs' more meaningful and integrated PCK development. Modeling a teaching strategy also contributes to PSTs' self-efficacy beliefs (Bandura, 1986), since it serves as a vicarious experience in which individuals form their self-efficacy beliefs through observation of others' behaviors. Teachers' beliefs also closely relate to their choice and use of instructional strategies (Tarkın, Uzuntiryaki-Kondakci, Akin, Demirdöğen, & Aydin, 2015). Instead of solely telling students how to apply argumentation as a teaching strategy, modeling argumentation on a particular chemistry topic from the curriculum contributes to PSTs' self-efficacy beliefs regarding their own use of argumentation.

Constructivist epistemology assumes that learners construct their own knowledge. However, learning can only take place when new information is built into and added onto an individual's current structure of knowledge, understanding, and skills (Pritchard, 2005). Piaget (1972), one of the pioneers in personal constructivism, describes learning as an adjustment to environmental influences through the processes of assimilation, accommodation, and disequilibrium. Disequilibrium occurs when there is a mismatch between what is already known and what is to be learned. In these circumstances, the learner accommodates existing knowledge. Piaget's notion of disequilibrium constructs the basis of our practice in this class because PSTs come to class with many views about teaching and learning (Uzuntiryaki, Boz, Kirbulut, & Bektas, 2010). Therefore, at the beginning of the class we ask PSTs several questions about argumentation and its use in teaching to elicit their beliefs about teaching and learning through argumentation. Moreover, enabling PSTs to experience argumentation as a teaching strategy creates disequilibrium in their beliefs about the applicability of reform-based teaching strategies. Also, PSTs construct their knowledge about argumentation by actively engaging with the strategy. A pioneer of social constructivism theory, Lev Vygotsky (1978), believed that human mental abilities develop through the individual's interactions with the world. Vygotsky referred to the transformation of an interpersonal process (human-to-human interaction) into an intrapersonal one as internalization (Vygotsky, 1978). Internalization occurs within the zone of proximal development, which refers to the distance between the actual developmental level and the potential developmental level. Instructional scaffolding as a teaching strategy originates from Vygotsky's socio-cultural theory and his concept of the zone of proximal development. During implementation of instructional scaffolding, first, the teacher models how to perform a difficult task. Modeling the use of argumentation as a strategy for teaching a particular chemistry topic forms a basis for us to scaffold PSTs knowledge and use of argumentation.

So far, we have elaborated on why we use argumentation to provide a clear picture of our course, and on the basic premises that explain why we structure a lesson in a particular way. For example, we model an argument-driven inquiry on the topic of chemical reactions in a way that has already been described by Sampson (2009) and Sampson et al. (2009). Therefore, this lesson must come after the lesson when PSTs learn about inquiry as a teaching strategy. Additionally, they need to know what an argument is beforehand, so we introduce argument and its basic components (i.e., claim, data, warrant, backing, qualifier, and rebuttal) (Toulmin, 1958) before the class through the use of a concept cartoon in which a family engages in argumentation on university choice (Demirdöğen, Yeşiloğlu, & Köseoğlu, 2015). We also give argument examples from chemistry (e.g., Solutions that include dissolved ions are called electrolytes [claim, which is the statement that has to be supported or disproved (i.e., explanations seeking to interpret natural phenomena constitute a special sort of claim)]. Conductivity is ensured through dissolved and moving ions [warrant, which is a statement that relates the explanation with evidence]. Table salt forms sodium and chloride ions when dissolved in water [backing, which supports the justification, appealing, for instance, to theories]. Therefore, salt water always [qualifier, which explains the grade of certainty and uncertainty of an argument, for instance "probably", "for sure", "it depends"] conducts electricity [data, which are observations, facts or experiments that are used to evaluate claim]. If ions are not formed when the matter dissolved in water, the matter is not an electrolyte [rebuttal, which acknowledges the restrictions or exceptions to a claim]). PSTs also construct their own arguments on both a daily-life issue and a chemistry topic. Hence, PSTs come to the class where they learn about argument-driven inquiry already knowing about argument. In the following section we will describe our lesson step-by-step for clarity. We use quotation marks to indicate dialogues between instructors and PSTs in the flow of the lesson, whereas other statements describing what we do during the lesson are indicated without quotation marks.

> "We continue to enrich the subject-specific instructional strategy component of your PCK. Today, you will learn about argument-driven inquiry. Since you have already learned about inquiry and argument, we will mostly focus on argumentation as a teaching strategy while revisiting your knowledge about inquiry as an instructional strategy. We will model argument-driven inquiry on the topic of chemical reactions. We will act as chemistry teachers while you act as high school students. Before we start, we want you to answer the following questions regarding your ideas about argument and inquiry-based learning.
>
> - What do you think about how you encourage students to construct argument during your teaching?
> - What do you think about the applicability and usability of argumentation in chemistry teaching?
> - At which point in inquiry-based learning can you encourage your students to construct arguments?"

After PSTs answer the questions above, we conduct a whole-class discussion on their ideas. We see this discussion as an assessment opportunity where we are able to collect evidence regarding what PSTs understand about inquiry-based learning and argument. This is the point when we also revisit their knowledge about those strategies. We move on to modeling argument-driven inquiry on chemical reactions (as described in Sampson, 2009 and Sampson et al., 2009) after this class discussion.

> "First of all, answer the following questions regarding argument-driven inquiry as a chemistry teacher.
>
> - What are the basic components of the argument-driven inquiry instructional model?
> - How does argumentation as a teaching strategy align with your science teaching orientation?
> - Which chemistry topics are more suitable to teach with argumentation?
> - Which difficulties may you encounter while using this strategy?
> - What is the teacher's thinking when planning and implementing argumentation for teaching this topic?
> - What are the ways to increase effectiveness of argumentation for different types of students?
> - In response to what kind of learning difficulties and alternative conceptions do you use argumentation?
> - Which component of your PCK develops as a result of this argumentation modeling experience?
> - How does argumentation as a teaching strategy support the chemistry curriculum (e.g., vision and objectives)?"
>
> We are ready to start argument-driven inquiry on chemical reactions. You will work in collaborative groups. Please form groups of four or five peers. Beginning from this moment, we ask you to act as high school students while thinking as a chemistry teacher and reflecting on your argument-driven inquiry modeling experience. What is your task today? You have already seen many chemical reactions. You have also learned how to recognize the evidence of a chemical reaction. These include a color change, the formation of a solid, the production of bubbles, change in pH, or a change in temperature. Although these are the evidences, some of them (e.g., formation of bubbles and change in temperature) do not prove that a chemical change occurs since they also happen during physical changes (e.g., boiling and crystallization). You should keep that in mind when interpreting your evidence based on explanations, as they are not proof. Chemists describe those reactions by the use of chemical formulas. You have learned how to read chemical formulas and how to balance them. But if we mix two or more reagents together, how can we figure out what products are formed? In this investigation, you will learn how to determine which products are formed during a chemical reaction. Your duty is to determine the balanced chemical formula for the following reactions.

$HCl_{(aq)} + Zn_{(s)} \rightarrow$

$HCl_{(aq)} + NaHCO_{3(s)} \rightarrow$

$CuCl_{2(aq)} + Al_{(s)} \rightarrow$

$Al_{(s)} + H_2SO_{4(aq)} \rightarrow$

$CuCl_{2(aq)} + Na_2CO_{3(aq)} \rightarrow$

$CuCl_{2(aq)} + AgNO_{3(aq)} \rightarrow$

You will work as collaborative groups in order to develop and implement a method to address the problem. The materials available for your investigation are as follows: drying oven, test tubes, alcohol burners, beakers, Erlenmeyer flasks, lab goggles, well plates, rubber stoppers, pH paper, wood splits, and other supplies as requested. Write out an investigation proposal that describes how you generate and analyze your data. Your first step in this investigation will be to gather evidence about the chemical reactions. You can create a data table in your notebook where you can record your observations about each chemical reaction. We will circulate from group to group to serve as a resource person for you as you complete your work."

At this step, we try to ensure that students think about what they are doing and why they are doing it as they gather data. We ask probing questions, such as, "How do you know that your data is reliable?" "What else do you need to figure out?" or "Do you have enough data to support your ideas?" After we circulate the groups to give feedback about their investigation, the collaborative groups implement their plan. During implementation, we recirculate the groups and ask probing questions: "Is there a precipitate production?" "Did you observe a gas release?" "Did the pH change?" "Which physical states of matter did you observe in your beaker?" We then address the class collectively with further instructions. "Prepare a whiteboard that you can use to share and justify your ideas. Your whiteboard should include all the information shown in the following diagram (Figure 1)."

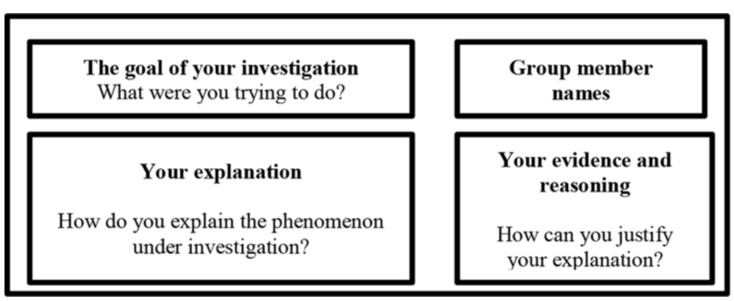

Figure 1. Diagram showing the structure of the whiteboard

> "To share your work with others, we will be using a Round-Robin format. This means that one member of the group will stay at your work station to share your group's ideas while the other group members go to the other groups one at a time in order to listen to and critique the explanations developed by your classmates. Remember as you critique the work of others, you have to decide if their conclusions are valid or acceptable based on the coherence of their explanation and how well they are able to support their ideas with appropriate evidence and reasoning. In other words, you need to determine if their argument is persuasive and convincing. To do this, ask yourself the following questions:
>
> - Is their explanation sufficient (i.e., it explains everything it needs to) and coherent (i.e., free from contradictions)?
> - Did they use genuine evidence (i.e., did they organize their data in a way that shows a trend over time, a relationship between variables, or a difference between groups) and did they use enough evidence to support their ideas (i.e., did they use more than one piece of evidence and are all their ideas supported by evidence)?
> - Is their evidence of high quality? In other words, is their evidence valid (they used appropriate methods to gather the data) and reliable (they attempted to reduce error in their measurements or observations)?
> - Is there any counterevidence that does not support their explanation?
> - How well does their explanation fit with other theories and laws that are used in science to explain or describe how the world works?
> - Is their reasoning adequate (they explain why the evidence was used and why it supports the explanation) and appropriate (rational and sound)?"

After completion of the Round-Robin poster-session, we lead a discussion in an effort to synthesize all the various perspectives into one "class" explanation that is the most valid or acceptable way to scientifically explain each chemical reaction. We also ask students to prepare a persuasive investigation report that consists of three sections. "Each section should provide an answer for the following questions. Section 1: What were you trying to explain (or figure out) and why? Section 2: How did you go about your work and why did you conduct your investigation in this way? Section 3: What is your argument? Your report should answer these questions in two pages or less. This report must be typed and any diagrams, figures, or tables should be embedded into the document. Be sure to write in a persuasive style; you are trying to convince others that your explanation is acceptable or valid!"

Once the reports are completed, we start talking about the basic steps we have completed so far in argument-driven inquiry. By revisiting their experiences, both as high school students and as teachers, we discuss how we have accomplish the following steps in an argument-driven inquiry instructional model: "*The identification of a task* that creates a need for students to make sense of a phenomenon or solve a problem; *the generation and analysis of data* by small groups of students using a method of their own design; *the production of a tentative argument* by each group that articulates and justifies an explanation in a medium that can be shared with others; *an argumentation session* in which each group shares its argument and then critiques and refines its explanations; and *an investigation report* written by individual students that explains the goal of the work and the method used, and provides a well-reasoned argument."

> Argument-driven inquiry includes three more steps for completion. Due to time limitations, we will explain what should be done in each step instead of enacting them. The remaining steps in argument-driven inquiry are *a double-blind peer review* of these reports to ensure quality and generate high-quality feedback for the individual authors; *the subsequent revision of the report* based on the results of the peer review; and *an explicit and reflective discussion about the inquiry*.

In explaining the double-blind review process, we introduce a sheet including the criteria used to evaluate the quality of the investigation reports (Sampson et al., 2009).

To provide a more comprehensive picture, we make a presentation about argumentation as a subject-specific teaching strategy at the end of the lesson. In this presentation, we focus on argumentation strategies used in classrooms and laboratories (Osborne, Erduran, & Simon, 2004), and the role of students and teachers in argumentation (Erduran & Jiménez-Alexander, 2008). This presentation serves as a context in which PSTs explicitly reflect on the questions we provide at the beginning (e.g., How does argumentation as a teaching strategy align with your science teaching orientation? How does argumentation as a teaching strategy support the chemistry curriculum?). Hence, we find a way to make their tacit PCK explicit. The explicit-reflective nature of the class is fruitful in enhancing PSTs' meaningful and integrated PCK development. Moreover, PSTs are more capable of identifying difficulties that they may encounter in their future teaching practices while implementing argumentation if they experience the method itself as learners of science. They also more confidently decide which chemistry topics they can use argumentation to teach. Their experiences in this class are valuable in challenging their beliefs about the inapplicability of reform-based teaching strategies in a class or laboratory.

ASSESSMENT

The CoRe for Assessing PSTs Lesson Plans

Both the literature on teachers' knowledge bases and our experiences as teacher educators led us to use CoRes for assessment purposes. The literature states that "…if preservice teachers were offered meaningful ways of defining, assessing, and explicitly developing PCK," (Nilsson & Loughran, 2012, p. 700) we would have the potential to solve teacher education programs' problems with regard to meeting their intended objectives. Our experiences using a standard lesson plan format indicated that PSTs prepared a lesson plan in which the objectives, instructional strategy, and assessment were disconnected (Aydin et al., 2013). Thus, we decided to utilize a revised version (Aydin et al., 2013) of the original CoRe (Loughran et al., 2004).

Although we introduced the CoRe earlier, we think that it deserves more explanation. The CoRe is a tool that was originally developed for the purpose of uncovering, documenting, and portraying science teachers' PCK in relation to particular science topics (Loughran et al., 2004). The CoRe is a two-dimensional matrix including components of Magnusson et al.'s (1999) PCK model in the rows and important concepts or big ideas from the topic to be taught in columns. The teacher, taking into account curriculum objectives and instructional time, determines important concepts or big ideas. Prompts in the rows help to uncover the teacher's PCK component in relation to a particular idea. We prefer to use a revised version (Aydın et al., 2013) of the original CoRe because we need clearer prompts in our context. Moreover, the original CoRe does not explicitly require teachers to state the topic and grade level that they are teaching or to review the curriculum. However, the revised CoRe includes three additional prompts: "chemistry topic/content area," "grade level," and "curriculum objectives to be addressed." Both the matrix nature of CoRe and the group work aspect of the CoRe provide meaningful ways for us to stimulate PSTs' integrated PCK development. Therefore, using CoRes for assessment purposes helps us to identify both to what degree PSTs develop each PCK component and the interplay among components. Table 2 presents how each prompt in the CoRe format helps us to learn about particular components of PSTs' PCK.

CONCLUSION: STRENGTHS AND AREAS FOR IMPROVEMENT

The Components of the Course That Work Well

In this course, PCK introduction, use of CoRes, and microteachings work well for both PSTs and for the instructors, who want to support PSTs' development in their teaching. Introducing PCK provides us with a shared language for planning and enacting teaching. It is also useful for PSTs, who need specific and clear information and ideas when starting their teaching career. In this respect, CoRes also supports their development because it provides specific areas that they need to focus on. Finally, after studying teaching at a theoretical level, they start to teach and realize how difficult it is. PSTs stated that although microteachings take about 15 to 20 minutes, they require at least 3 to 5 days to plan. They understand that teaching means coordinating the many different components necessary for facilitating learners' knowledge construction.

Areas to be Improved in the Course

Although we provide many different experiences to enrich PSTs' development, we think that we may in the future include an observation in which PSTs have a chance

Table 2. How each prompt in CoRe helps us to learn about pre-service teachers' PCK

Prompt	*What we have learned*
Chemistry Topic/Content Area	This indicates whether PSTs reviewed the curriculum.
Grade Level	This indicates whether PSTs reviewed the curriculum.
Curriculum objectives to be addressed (Objectives related to the topic stated in curriculum)	This indicates PSTs' knowledge of curriculum regarding mandated goals and objectives. Also, if a PST selects a particular objective considering his/her orientation this indicates interplays between his/her orientation and the curriculum (e.g., including an objective such as to give examples of fast and slow reactions from daily life indicates teacher's everyday coping orientation).
What concepts/big ideas do you intend students to learn? (The main concept or idea of which PSTs think that they are important for students to learn.)	The sequence of big ideas indicates whether or not PSTs consider prerequisite ideas for learning (e.g., placing average vs. instantaneous rate concepts after definition of rate of reaction).
What do you expect students to understand about this concept and be able to do as a result? (Guides PSTs in thinking about specific learning outcomes related to each big idea when designing the instruction.)	This indicates whether PSTs consider all dimensions of students' learning when designing instruction (e.g., both defining and differentiating average and instantaneous rate, indicating average and instantaneous rate on concentration-time graph, and solving problems on the topic).
Why is it important for students to learn this concept? (Rationale)	This indicates whether PSTs consider their orientation when determining concepts (e.g., if a PST states that it is important for students to learn rate of reaction to understand the reactions in our body, this indicates his/her everyday coping orientation), prerequisites for learning (e.g., if a PST states that defining rate of reaction is important to understand the rate of reaction formula, this indicates his/her knowledge of learner in terms of prerequisites), and horizontal and vertical relations in curriculum (e.g., stating that rate of reaction is important for learning chemical equilibrium indicates teacher's knowledge of curriculum).
As a teacher, what should you know about this topic?	This indicates PSTs' PCK in understanding level. If a PST reflects and evaluates his/her knowledge considering all PCK components this indicates his/her PCK understanding.
What difficulties do students typically have about each concept/idea?	This indicates how and to what extent PSTs consider potential difficulties.

Prompt	*What we have learned*
What alternative conceptions do students typically have about each concept/idea?	This indicates whether PSTs are aware of all potential alternative conceptions.
Which teaching strategy and what specific activities might be useful for helping students develop an understanding of the concept?	This indicates PSTs' knowledge of subject– and topic-specific instructional strategies. Also, several interplays among PCK components are evidenced. If a PST specifically selects an instructional strategy to achieve curricular objectives (i.e., interplay between curriculum and instructional strategy), to address students' difficulties and alternative conceptions (i.e., learner and instructional strategy), or to realize his/her orientation (i.e., orientation and instructional strategy), this shows interplay among PCK components.
In what ways would you assess students' understanding or confusion about this concept? (Formative assessment and summative evaluation)	This indicates PSTs' knowledge of assessment in terms of what and how to assess. Also, several interplays among PCK components are evidenced. Interplays are shown if PSTs specifically assess curricular objectives and relations, including the horizontal and vertical (interplay between curriculum and assessment), students' difficulties and alternative conceptions (interplay between learner and assessment), whether they realized their orientation (e.g., asking daily-life questions indicates interplay between an everyday coping–related orientation and assessment), or his/her instructional strategy to revise the strategy (i.e., interplay between assessment and instructional strategy).

to observe experienced teachers' practice in high schools. During the end of the semester, PSTs may visit real classrooms and observe how teachers enact instructions, address learners' difficulties, use curriculum, and assess learners' understanding. Due to course loads of instructors in the university and mentor teachers in high schools, and the paper work necessary for the partnership between NME and universities, the integration of observation of experiences teachers' classroom practice is difficult for now. Another point that we need to improve in this course is including mentoring support, which would be provided by teaching assistants in the course. We included mentoring in a practicum course and observed an incredible development in PSTs' teaching. Before the preparation of microteachings, it is possible to provide mentoring for supporting PSTs' microteaching planning and enactment.

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9. IMPLEMENTING PCK TOPIC BY TOPIC IN METHODOLOGY COURSES

A Case Study in South Africa

INTRODUCTION

The history of South Africa presents a story of a divided education system with policies deliberately designed for disparity in the quality of provision. Prior to 1994, education policy in the country was used to constrain political, social, and economic development of people of colour, who are in the majority. Twenty years on, the widespread after-effects of this segregated education policy continue to trouble the present society from all quarters. For science education, the effect manifests as under-performance evidenced in both international studies and local research. Spaull (2013) points particularly to a weakness in South African teachers in relation to content knowledge. His findings are no surprise, as the majority route for the training of black high school science teachers in the apartheid era was through primarily rural teacher training colleges with few resources. These colleges offered three-year post-school diplomas delivered primarily through transmission teaching. Science and mathematics education researchers argue that improvement in education lies at the heart of teacher development, and furthermore with the teacher education system that produced new teachers (Taylor, 2015). As part of the post-democracy reforms in education, the teacher education system was radically re-organized, entailing the closing of most teacher training colleges. The remainder were merged with higher education institutions (HEIs), thereby making initial teacher education (ITE) the responsibility of HEIs only and turning teaching into an all-graduate profession.

Today, three pathways are possible routes to access for initial teaching that leads to a qualified teacher status: (i) a four-year Bachelor of Education degree (BEd), (ii) a three-year undergraduate Bachelor degree capped by a one year professionally-focused Post Graduate Certificate in Education (PGCE) and (iii) A technical Diploma capped by a professionally focused Advanced Diploma in Teaching which exits at a slightly lower level to graduate status, being that of a diploma. This third option is limited to vocational based programmes. The BEd degree and the PGCE are most appropriately located at a degree level. According to the national policy on Minimum Requirements for Teacher Education Qualifications (MRTEQ) (Department of Higher Education and Training, 2015), the primary purpose of all ITE

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qualifications is to certify that the holder has specialised knowledge as a beginning teacher in a specific phase (grade level) and/or subject. This specialisation can take one or more of a variety of forms, all of which are associated with competence in subject matter knowledge. Specialisation can be linked to a phase (for example, the Foundation Phase – grades 1–3), a subject (for example, Mathematics or English), or a combination thereof. The BEd is designed to include 480 credits, usually studied over 4 years of full-time study. The PGCE is usually studied over one year of full time study and follows a general degree that includes the study of subjects that provide sufficient disciplinary learning.

As mentioned above, the national policy (Department of Higher Education and Training, 2015) calls for the development of teachers in areas of specialization. To this end, students at institutions of Higher Education, nationally, are thus registered according to their desired school phase or combinations of specialization. A school phase refers to a level in our school system hierarchy that is comprised of three successive school grades/academic years. The options available are: (i) BEd in Foundation Phase Teaching (this refers to the first four Grades of the South African schooling system, which are Grades R[1], 1, 2, and 3); (ii) BEd in Senior Primary Phase Teaching (school Grades 4-6). The Senior Primary Phase is also referred to as *Intermediate Phase* and this is the phrase used in the discussion below; (iii) BEd in Senior Phase (school Grades 7–9); and (iv) Further Education Training (FET) Teaching (school Grades 10–12). In the South African context, largely, a primary school offers Grades in the Foundation and Intermediate phases and a Secondary school offers Grades in the Senior and FET Phases. Variation from this norm occurs with schools called Intermediate schools which may offer Grades in the Intermediate phase only.

Within each phase, pre-service teachers are encouraged to take a major course in a discipline of specialization and a second sub-major course which may be in a different or same discipline of specialization. According to the national policy, the delivery of learning within each phase is to contain a knowledge mix in three categories: the first category is *disciplinary learning*, which refers to the study of education and its foundations, and the development of specialised subject matter knowledge. For FET and Senior Phase teaching this must be in the disciplines that underpin the school subject to be taught. The second category is the *Pedagogical Learning*, which includes general pedagogical knowledge and the bulk being allocated to Pedagogical Content Knowledge (PCK) for the specific subject of specialisation(s). The third category is *Practical Learning* or school-based work, which is supervised and assessed as a teaching practice. Pre-service teachers within a phase are required to be exposed to school-based supervised experience for a minimum of 16 weeks and a maximum of 24 weeks over the four years of the degree. In any given year, a maximum of 10 weeks should be spent in schools and at least three of these should be consecutive. In practice this translates to two 3-week periods spent in school in every semester.

Methodology Courses in Secondary School Science Education

Our institution offers two streams of science education courses for the BEd degree for teaching in Secondary Schools. These are: the life science and the physical science education options. The physical science education stream combines the chemistry and physics domains of the science discipline as these domains appear as a joint subject in the South African secondary school curriculum, where the two components are given equal weight and thus are taught as such in schools. Pre-service teachers are able to choose either stream at the third year of their study and continue to graduate in the chosen subject as a major in the fourth and the final year of the degree. They are also required to choose a second school subject as a sub-major. A major subject would be a subject taken to the fourth year of study and a sub-major a subject taken to a maximum of third year of study. Our institution offers options to take the sub-major in a different discipline, such as mathematics, or in the same discipline, such as life or physical science, by running two versions of third year courses in each of these subjects, respectively. For example, a student may have life science or a physical science as a major combined with mathematics as a sub-major; alternatively, a pre-service teacher may have life science or physical science each as both a major and sub-major.

All students who register for the BEd degree for teaching in Secondary Schools take a course called *Natural Science* in their first two years of the degree. This course reflects the content of its namesake in the Senior Phase school curriculum, as it comprises content in chemistry, physics, life science and earth science in equal proportions. The course is geared to prepare pre-service teachers to also teach the three school Grades of the Senior Phase, a Phase that precedes the three Grades in the final FET phase. Thus, a graduate teacher from the life or physical science stream, when employed in a Secondary school, will be able to teach classes in both the Senior and the FET Phases.

The delivery of the degree is such that the subject content knowledge and the pedagogy/methodology courses run in parallel. There is a methodology course for each academic year. Overall, a pre-service teacher would be exposed to a total of five methodology courses over the four years of study: two Natural Science methodology courses in the first two years of study, two methodology courses in the major subject across years three and four and one methodology course in the sub-major subject in year three. Each of the methodology courses has two semesters in a year. A semester is made out of 36 hours of teaching spread over 12 weeks. Each week has three periods of just under one hour each for teaching. Integration across the content and the methodology courses is achieved by deliberate planning such that the discussion in the methodology courses is simultaneously based on topics that are taught in the content course. This alignment is sometimes not possible; in such cases, a topic that was previously taught, in the previous academic year, may be chosen. The school-based practical experience is an integral component of the BEd degree allocated

6 weeks in each academic year. Three consecutive weeks are allocated in the first semester, while the second set of consecutive weeks is used in the second semester.

PLANNING: DISCUSSION OF COURSE DESIGN

The importance of preparing preservice teachers to teach effectively is shared worldwide (Osman, 2010). However, for a country like South Africa, where the education system is adversely affected by the policies of the past, there is a moral obligation to continually scrutinize the nature of the curriculum offered to Initial Teacher Education (ITE); firstly to guard against a repeat of the past and also to seize the opportunity rendered by the present curriculum to offer quality ITE as a potential means of addressing the historical crisis (Osman, 2010; Rusznyak, 2015). Given the concerns about subject matter knowledge highlighted above, the consideration of the value of Pedagogical Content Knowledge (PCK) for science education as the knowledge that ought to be taught to pre-service teachers was most attractive as a starting point for our courses. PCK has been the subject of discussion by many science education scholars since Shulman's (1986) introduction of the theoretical construct (e.g. Aydin et al., 2015; van Driel, Verloop, & de Vos, 1998). From a learning to teach perspective, the understanding of Pedagogical Content Knowledge as topic-specific (Rollnick & Mavhunga, 2015) has provided a framework from which we have designed our methodology courses. In addition, the recognition of the construct as part of Pedagogical Learning, cited in our newly revised national policy on teacher development – the MRTEQ, has given a much appreciated renewed emphasis on what is to be learned by prospective teachers with an improved alignment to the science education research literature.

Purpose and Outcomes

The purpose of our science methodology courses is to develop a specific depth and specialisation of knowledge, together with practical skills that comprise a professional teacher competence for teaching core topics in a specified science discipline, (Life Science, Physical Science or Natural Science). Given the time constraint in the methodology courses, it is not possible to use all topics in a discipline as examples when developing the competence to teach. Thus, we have adopted a strategy where two to three core topics in a discipline are selected. By core topics we mean those topics that encompass several sub-concepts that link to other topics more explicitly. For example, in chemistry, stoichiometry is fundamental to the successful understanding of many different types of chemical reactions such as redox. Also, the core topics are contained as school topics in the school curriculum. Linked to this purpose are three major outcomes, producing graduate science teachers who have:

- Specialized PCK knowledge in core topics in the discipline of Natural Science and that of their major stream.
- An understanding that teaching is about transformation of their comprehension of concepts and a belief that learners are central in their planning and choice of pedagogical approaches.
- Knowledge of how to pedagogically transform comprehended knowledge when engaged in planning and teaching a new topic.

Our methodology courses are heavily based on PCK. Central to the theoretical framework of PCK used in our courses is the idea of transformation of content knowledge in specific topics (Geddis, Onslow, Beynon, & Oesch, 1993). We have conceptualized PCK at a topic level as the knowledge to transform topic concepts into versions that are accessible for understanding by a learner. This pedagogical transformation of content emerges from thinking about the topic from the perspective of (i) Learner prior knowledge, including misconceptions, (ii) Curricular saliency, (iii) Knowledge of what is potentially difficult to learners, (iv) Representations and (v) Knowledge of topic-specific conceptual teaching strategies. These five content-specific components are regarded as a framework that could be applied to any topic to achieve pedagogical transformation of its concepts. Unpacking the construct of PCK in this manner has offered us a tool that has been used to assist pre-service teachers with understanding the construct one topic at a time, and also learn a framework to apply to new topics that may not have been covered explicitly in ITE or that may also be a result of curriculum changes once in practice. PCK acquired through the use of this framework has been termed Topic Specific Pedagogical Content Knowledge (TSPCK); more specifically referred to as espoused TSPCK at a planning level and then enacted TSPCK when pre-service teachers are afforded teaching opportunities in schools as part of the ITE. The implementation of the construct of TSPCK in our methodology course enables pre-service teachers' development of discipline specialization (referred to at a national policy level by the MRTEQ as *Disciplinary Learning*) which includes the study of specific specialised subject matter relevant to academic disciplines underpinning teaching subjects.

Implementation of TSPCK in the Early Stages of the BEd Degree in Natural Sciences

While the value of the implementation of PCK, particularly TSPCK, in science ITE has been received positively by the science education community (Rollnick & Mavhunga, 2015), implementation of the construct with pre-service teachers, particularly in the early stages of their study, remains a challenge for a number of reasons. First, as mentioned previously, pre-service teachers come to the methods courses with disparate backgrounds in terms of their content knowledge, which is largely poor given the South African context. Second, teacher educators generally do not have time to model lessons related to every core curriculum topic in which they could demonstrate best practices (Grossman, 2011).

In the first year methodology course, PCK is introduced in a very broad way. What is emphasized at this level is the fact that PCK is the knowledge that bridges content knowledge and ways of teaching it. Also introduced at this level is the pedagogical reasoning process as suggested by Shulman (1987). In the second year, the pre-service teachers start to look at their development of the construct in selected Natural Science topics. Two topics are used; chemical bonding and cell structure and function. Both topics are included in the school curriculum for Natural Science.

In order to bring the topic-specific nature of PCK to the fore, only three of the five content specific components of the TSPCK framework are used (Mavhunga & Rollnick, 2013). These are (i) Learner prior knowledge, (ii) Curricular saliency and (iii) Representations that are specific to the topic. These three content-specific components were chosen as they are reported to reveal the topic-specific nature of PCK more visibly than others in studies that have a focus on science teachers' topic-specific PCK (e.g. Aydin et al., 2015; Aydin, Friedrichsen, Bozc, & Hanuscin, 2014). The components are discussed one at a time. For an example, the discussion on the component of Learner Prior Knowledge in Chemical Bonding focusses on common misconceptions of the topic, such as the adoption of a molecular framework for explaning ionic bonding. Beginning pre-service teachers are provided with research articles explicitly discussing misconceptions in the topic (e.g. Tan & Treagust, 1999). In this approach, content found lacking is explicitly discussed as the opportunity arises.

To sum up, in the first year of the BEd degree, PCK is first introduced as a broad concept relying mostly on the definition from Shulman (1986), and the process of pedagogical reasoning and action (Shulman, 1987). In the second year, the topic-specific nature of PCK is introduced. Pre-service teachers begin to develop PCK in core topics by explicitly developing their understanding of the topic from a perspective of three selected content specific components and how considerations from these components interact in formulating teaching plans. In the both the first and the second year methodology courses, discussion on PCK takes up 80% of the course content. The importance of observation and reflection as well as class management are also discussed in the first and second year of study, respectively. These topics are introduced to start preparing pre-service teachers for school teaching experience where they observe teaching by expert teachers in the first year and start to handle actual teaching in the second year.

Implementation of TSPCK in the Science Major Streams in the last two years of the BEd Degree

The science education methodology courses in the last two years of the BEd degree are geared at preparing students for specialization in either the Life Science or the Physical Science stream and relate to the FET curriculum (grades 10–12) in Secondary schools. They are characterized by a strong focus on developing TSPCK in core topics of the Secondary school curriculum. At the beginning of the year, the understanding that PCK is topic specific is re-visited and the definition of TSPCK as a construct defining the topic specific nature of PCK is made explicit. All five components of TSPCK are emphasized at this stage of the programme. Clarity is also given that the aim is not only to think about a topic from the perspective of the components but equally important is recognition on how the components interact with each other. Pre-service teachers must develop the capability to demonstrate such interactions in lesson planning and eventually in classroom practice during school teaching experience. The topics used in the third and fourth year methodology courses are determined largely by two factors. Firstly, that they should have been covered in the separate, parallel content course or they are covered at about the same time as they are discussed in the methodology course. Secondly, that they are in the secondary school curriculum. Often, a discussion will ensue between the educators of the content and the methodology courses, or in other cases the same educator is teaching both the content and the corresponding methodology course. Typical content topics used to develop TSPCK include: Meiosis, Mitosis, Embryology and Circulatory systems (life science stream); and Chemical Equilibrium, Electrochemistry, Organic Chemistry, Stoichiometry, Kinematics, Electric Circuits and Electrostatics (physical science stream). In each of the senior academic years (3rd and 4th year), pre-service teachers would experience a discussion of TSPCK at least in two topics in a given domain (i.e. two topics in Chemistry, in Physics, and in Life Science) according to the major they have chosen. One of the topics would have been discussed explicitly in detail over a long time (six weeks), and the second topic used for summative assessment. Additional topics related to other pedagogical knowledge aspects of education such as inquiry in science, assessment in science, practical work, and class management are discussed over the last six weeks of a semester following a detailed discussion on TSPCK. Discussion of general pedagogy occurs at the end of the semester because pre-service teachers are being prepared for a school teaching experience just before the semester ends.

In summary, the science education methodology courses in the 3rd and 4th years of the BEd degree programme have an explict foucs on developing specialized professional knowledge in teaching core topics. Furthermore, the exposure to discussions on TSPCK in several topics using the same framework, provides pre-service teachers with an opportunity to develop awareness of the consistency of the framework and yet also the variety and difference in the knowledge generated. It is intended within the constraints of time in the methodology courses, that pre-service teachers would appreciate the TSPCK framework as a reference to fall back on when faced with planning and teaching for a new topic.

Strategy Behind the Assessment Used

Assessment is based on continuous, formative and summative types of assessment. As one of the outcomes of the course is to promote appreciation of TSPCK as a possible framework to use when faced with planning and teaching a topic, assessment serves two purposes in the methodology courses. The first is to assess the extent of acquisition of TSPCK in the topic of the intervention. This is the topic that the TSPCK content specific components would have been discussed explicitly and in detail. The second purpose is to assess the extent to which pre-service teachers are able to transfer their learnt knowledge of the TSPCK framework and how the components could be used interactively to transform content of a novel topic, thus developing their TSPCK in the new topic. The tools used in each case could be a combination of specially designed instruments that measure the quality of TSPCK in the topic and/or the development of Content Representations (CoRe) (Loughran, Berry, & Mulhall, 2004) in the topic of intervention. The specially designed tool for TSPCK is a pencil and paper based instrument, which consists of tasks that would make explicit teachers' tacit TSPCK. The TSPCK test consists of five sections that correspond to the five components of TSPCK (Mavhunga & Rollnick, 2013), namely learners' prior knowledge, curricular saliency, what makes a topic easy or difficult to teach, representations and conceptual teaching strategies. Each section is considered as a test item with two to three sub-questions. The understanding of each TSPCK component and its interactions with other components are considered as windows into the quality of TSPCK. The tasks in the tool require responses from teachers that demonstrate both understanding of a component and the interaction of one or more other components. For an example, Figure 1 presents a sample test item.

The CoRe used in the course is modified from Loughran et al. (2004) to reflect explicit prompts on the five content specific components of TSPCK, as shown in Table 1.

CATEGORY D:

Le Châtelier's' Principle

Below is a student's written response in a class test designed to assess prior knowledge of students about Le Châtelier's' Principle.

Question:

What is the effect of adding more water to the reaction given below at equilibrium?

$$CH_3CO_2H(aq) + H_2O(l) \rightleftharpoons CH_3CO_2^-(aq) + H_3O^+(aq)$$

A student responded:

'More $CH_3CO_2^-$ (aq) and H_3O^+ (aq) will be formed, to counter act the effect of adding more water to the reactants. This will happen until a new equilibrium is reached'.

Following the student's response, how will you teach a lesson on predicting the effect of factors disturbing the equilibrium?

Figure 1. A sample test item from the TSPCK tool on the component of conceptual teaching strategies

Table 1. An adapted CoRe highlighting the five components of TSPCK

Curricular saliency	What do you intend the learners to know about this idea? *(original CoRe item – geared to capture subordinate concepts)*
	Why is it important for learners to know this big idea? *(original CoRe item – a potential window to observe any consideration of the other TSPCK components in the provided reasons)*
	What concepts need to be taught before teaching this big idea? *(original CoRe item – captures pre-concepts)*
	What else do you know about this idea (that you do not intend learners to know yet)? *(original CoRE item – captures what is considered peripheral)*
What is difficult to understand	What do you consider easy or difficult in teaching this big idea? Explain. *(new question added)*
Learner Prior Knowledge	What are the typical learners' misconceptions on this big idea? *(new question added)*
Representations	What representations will you use in your teaching? *(new question added)*
Conceptual teaching strategies	What conceptual strategies would you use in teaching this big idea? *(new question added)* What questions would you consider important to ask in your teaching strategy? (*adapted from original: captures teaching procedures)*
Reflections	What ways would you ascertain students' understanding *(adapted from original: captures specific ways to ascertain students' understanding*)
	What aspects of planning and teaching this big idea would you like to reflect on *(original CoRe item)?*

Table 1 shows what was added or modified to the CoRe in comparison to the original instrument. Windschitl, Thompson, and Braaten (2011) support the argument for the importance of providing novice teachers with support for effective teaching using "praxis tools". According to the authors, praxis tools embed theory about effective teaching into material resources or strategies that guide the planning and teaching process. The value of the CoRe in capturing and guiding the thinking of pre-service teachers has been demonstrated through a number of studies (e.g. Bertram & Loughran, 2014; Hume & Berry, 2010). On the other hand, the specially designed TSPCK tools for specific topics has been useful in developing insights into how pre-service teachers reason about a topic from an angle of the individual content components of TSPCK and in their interactive use. This has been an area of our research interest; providing an opportunity to explore the nature of TSPCK and its acquisition in ITE.

CLASSROOM PRACTICE: VIGNETTE OF A SIGNATURE TEACHER EDUCATION LESSON

A Lesson on TSPCK in a Second Year Methodology Class: The Component of Learner Prior Knowledge

As mentioned above, the discussions on TSPCK in a topic at this level are based on explicit discussion of three components of TSPCK. Each of the components are delivered over 2 weeks, where each week is comprised of a single period of 1 hour traditional lecture and a double period of 2 hours interactive tutorial time. The structure allows time for pre-service teachers to try out activities and receive valuable feedback. The traditional lecture is a combination of the lecturer providing information and some whole-group discussion, although the lecture is not as interactive as the tutorial sessions. Prior to the discussion, the theoretical construct of TSPCK is introduced. Reference is made to how it differs from the broader PCK construct at a discipline level, thus the importance of working within a specific topic (chemical bonding in this case) is noted. TSPCK is defined as having five content specific components, and these are named. Pre-service teachers are then made aware that only three of the components will be discussed explicitly while the other two are discussed implicity. The first component, *Learner Prior Knowledge,* is introduced. The component is explained as referring to knowledge about the topic that learners carry, including common misconceptions. A few examples of common misconceptions about chemical and bonding are discussed. These include, for example, the adoption of a molecular framework for explaning ionic bonding, and the misconception that atoms form bonds to satisfy the octet rule. In this approach, content found lacking is included and discussed as the opportunity arises, including suggestions for improving both pre-service teachers' and learners' understandings. This arena for discussing pre-service teachers' own misconceptions has proved to be a powerful mechanism for addressing challenges in pre-service teachers' content knowledge in the context of pedagogy (Friedrichsen, Van Driel, & Abell, 2011). The value of understanding a topic from the perspective of common misconceptions as a future teacher is discussed. We then discuss with pre-service teachers how they can learn about common misconceptions of a topic, since they have not necessarily been exposed to classroom practice. Pre-service teachers are pointed to research articles and discussion with expert teachers. Pre-service teachers are then provided with research articles explicitly addressing misconceptions in the topic (e.g. Tan & Treagust, 1999), and a set of tutorial questions that require them to identify a few more common misconceptions and suggestions for overcoming them, which is then discussed in a tutorial session.

The second component, *Curricular Saliency*, is introduced as knowedge that assists in developing a structural overview of a topic. This component has three features that are used to unpack and re-pack the structure of a topic. These are: (i) Identification of the most important meaning that, without it, learners would not develop adequate understanding of the content matter of the topic (Geddis et al., 1993). The concept of 'big ideas' is introduced as a way to identify and formulate the most important understandings. (ii) Understanding the pre-concepts needed prior to the teaching of a big idea and lastly, (iii) the sequencing of the identified big ideas. Analysing a topic from these three aspects develops pre-service teachers' understanding of curricular saliency about the topic. Pre-service teachers generally struggle with the formulation of big ideas. To help them in developing a mental picture of the topic, concept maps are introduced as a visual representation of the major and sub-major concepts of a topic. The major concepts in the topic are then used as anchors in formulating statements that express the most important understandings to be esablished about each one. Pre-concepts are identified from asking a question such as, "What concepts need to be first understood prior to teaching this big idea?" In order to establish a logical sequence for teaching big ideas, the following question is presented: "which big idea is needed in order to understand the next big idea?"

The last component, *Representation,* is introduced from the perspective of the value derived in using representations to simultaneously address different levels – macroscopic, symbolic and sub-microscopic levels in order to explain a concept (Davidowitz & Chittleborough, 2009). The pre-service teachers work in permanent tutorial groups throughout the six week period. The value of the tutorial lies in the actual struggle, the trial and error opportunity (Nilsson, 2008) afforded to pre-service teachers to plan for possible strategies to correct a particular misconception, and to formulate a big idea statement and use representations in a meaningful way. It is in the struggle and the presence of input from peers that the understanding of the topic from the perspective of learner prior knowledge is endorsed, and possible interaction of the TSPCK components emerges in the suggested correction strategies. Pre-service teachers are then required to present to the entire class how they would address a particular learner misconception in the topic. Feedback on both strong and weak aspects of the presentation from the entire class is encouraged. Due to time constraints, not all groups are able to present. Often, two to three presentations of 5 minutes each are allowed, and the session ends with a closing discusson. During this discussion, the educator explicitly provides examples of common areas of learning difficulty, which often draw interactively on considerations made from the three components of TSPCK in planning for teaching. The emphasis in the closing argument is in the explicit identification of possible component interactions emerging from the suggested strategies by pre-service teachers, and provinding more examples. Pointing out explictly the component interactions in pre-service teachers' suggested strategies always captures the interst of the entire class. The discussion on these three components as described lasts over a period of six weeks, with three hours per week.

A Lesson with all Five Components of TSPCK in 3rd and 4th Year Methodology Classes

The structure of the methodology courses in a week is similar to that described above for the second year classes. However, unlike in the second year classes, the discussion on TSPCK in a specific topic entails the explicit discussion of all five components of TSPCK in a sequence given in Table 2 below. Thus, each component of TSPCK is allocated only a single week for discussions, with the sixth and last week used for synthesizing all the discussions and capturing them into a CoRe. Table 2 presents a lesson series for the development of TSPCK in the topic, particulate nature of matter.

Pre-service teachers are assisted to relate each component of TSPCK to the topic of particulate nature of matter. Starting with the component of learner prior knowledge, focus is placed on common learner misconceptions in the topic. These are drawn mainly from the literature. Examples discussed include the thinking that the size of atoms increases when substances are heated (Ayas, Özmen, & Çalik, 2010). The discussion of strategies to counteract this misconception include, among others, reminding learners about the properties of atoms of specific elements as classified in the Periodic Table. Thus, if atoms were to change size, it would be impossible to classify them, as they may change identity and lose their location on the Periodic Table. The component of curricular saliency, like in the second year class, is explained as referring to three aspects. These are: the most important understandings to be established in the topic expressed as big ideas; the knowledge of pre-concepts needed prior to teaching a particular big idea and the sequencing of the teaching of the identified big ideas. For example, some of the statements that could be regarded as big ideas in the topic of particulate nature of matter include: "Substances are made up of tiny particles called atoms"; "There are empty spaces between the atoms." In order to generate big ideas, pre-service teachers were advised to first draw a concept map for the topic, where the major concepts of the map are turned into statements that demonstrate their most important meaning in the topic. For the component of 'What is difficult to understand,' the discussion identifies those concepts that are not necessarily misconceptions but create difficulty in understanding because of other prior knowledge. For example, learners may experience difficulty in understanding compression and expansion of air because of the empty spaces between the particles of air. The reason of this issue is because it is difficult to imagine empty spaces that are not filled by anything. The component of representations entails discussions on how representations at the macroscopic, symbolic and sub-microscopic levels are used interchangeably to support understanding of concepts in a topic. For the topic of particulate nature of matter, the use of representations showing the three

Table 2. Description of the TSPCK in particulate nature of matter intervention by component

Component	*Intervention*	*Specific examples used*
Learners' prior knowledge	Discussion on widely researched common misconceptions of the topic found in the literature. These are provided to pre-service teachers as drawn mainly from the literature. There are cases where pre-service teachers may share an experience encountered in a school-based experience.	• The misconception that the size of particles increases with increasing heat. • Phase change.
Curricular saliency	Discussion geared toward identifying the 'big ideas' and the corresponding subordinate concepts in a topic; sequencing big ideas; awareness of the foregrounding concepts, and knowing what is most important to understand in a big idea.	Big ideas: • All substances are made of tiny particles. • Particles are in constant motion. • Molecules have forces between each other. Prior knowledge needed: • Knowledge of the periodic table.
What is difficult to teach	Exploration of concepts considered difficult to learn, and pin-pointing the actual issues that make understanding difficult.	• There is an empty space between particles of matter. • There are different types of small bits of substances.
Knowledge of representations	Introduction of the three levels of explanations in chemistry at macroscopic, symbolic and sub-microscopic levels. Emphasis is placed on the power of using all three representations simultaneously in explaining a phenomenon.	• Use of a diagram simultaneously showing macro and sub-micro levels of representation of matter (see Figure 2).
Conceptual Teaching strategies	Discuss conceptual teaching strategies and how they are developed with consideration for the other four components.	• Strategically using the combination of macro, symbolic and sub-microscopic representations to illustrate different phases of matter. Paying particular attention to size of particles used to illustrate different phases ensuring they are of the same size.
Pulling it together	Introduction of Content Representations (CoRe) as a tool to capture thoughts as one thinks about content knowledge of a topic through the knowledge components of TSPCK.	• Construction of a CoRe using the big ideas listed above in the component of curricular saliency.

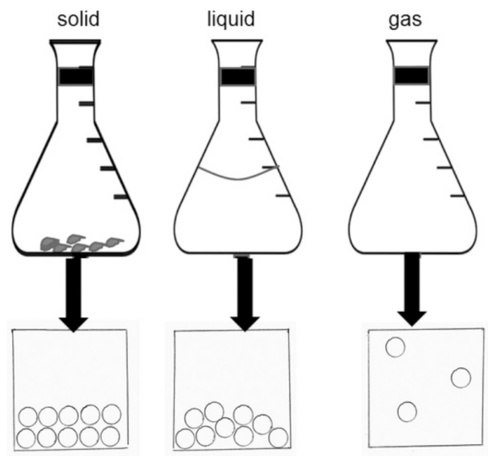

Figure 2. Representation for teaching particulate nature of matter (Rollnick & Mavhunga, 2017)

phases of matter was selected as an example on which to base the discussions (see Figure 2).

During discussions, it was shared that a common challenge in using these representations in a topic lies in how teachers tend to move from one form to another without making learners aware of the difference. Another issue is that educators need to be knowledgeable on different types of representations in a topic in order to choose those that would be most suitable for supporting the learning of the concept under discussion (Shulman, 1986). The discussion on conceptual teaching focused on the interaction of the different components by drawing on the considerations made above to generate a teaching plan. For example, pre-service teachers think about how the use of representations at different levels may be used to teach an aspect of a big idea that has been identified as difficult to understand – particular empty spaces between atoms. It should be noted that the discussion of a topic from this approach enables repeated opportunities to provide accurate content knowledge on the topic as it is needed, while emphasis is on the use of representations to support formulation of explanations when teaching. At the end of the discussion, pre-service teachers begin to develop an improved insight into the topic in a manner that distinguishes their content knowledge and aspects of their special PCK in the specific topic.

As with the second year methodology courses, the two tutorial periods per week offer pre-service teachers the opportunity to struggle practically through each of the TSPCK components discussed in that week. The unique feature in the class of 4th years is that they are encouraged to consider their school-based practical component of the degree as an opportunity to conduct a mini-research evaluating their use of the TSPCK framework in planning and in the actual delivery. The first school-based practical in an academic year often happens after the completion of the six weeks where TSPCK was introduced and worked through in detail in a given topic (particulate nature of matter in this case). During the school-based experience, pre-service teachers are required to teach various topics which may not include the topic in which they learnt TSPCK. Thus, their classroom teaching offers opportunities to evaluate how they apply their learnt ways of transforming content knowledge. In schools, they are under the mentorship of a practicing teacher whom may not necessarily have been briefed on the content to which the pre-service teachers have been taught. Before the pre-service teachers leave for their school-based experience, they are provided with a template for planning a lesson that uses the five components of TSPCK as prompts. They are required to use the template in planning their lessons and audio-record their own lessons. All ethical requirements such as asking permissions from the school, the teacher, learners and their parents for audio-recording the lessons are observed. On returning, the pre-service teachers are assisted in analysing and writing up research reports on the quality of TSPCK in their teaching.

ASSESSMENT: VIGNETTE OF A SIGNATURE ASSESSMENT

The signature assessment in the series of lessons on developing TSPCK in a given topic occurs in the sixth week in both the 2nd and the 4th year class, where the CoRe is introduced as a tool for capturing pre-service teachers' reasoning on each of the five components of the TSPCK in a topic. The CoRe used in the methodology courses is the modified CoRe as discussed earlier and shown in Table 1 above. Pre-service teachers first work in the permanent groups to identify the big ideas and then work individually to complete the rest of the CoRe. The activity to identify big ideas is a difficult activity, often achieved through group input by practicing teachers (Loughran et al., 2004). Pre-service teachers formulate their big ideas, as explained earlier, by accessing their content knowledge of the topic through drawing concept maps. The concept map activity assists in identifying major concepts from which the struggle to write statements about the most important understandings of a major concept ensues. The subordinate concepts that are linked to the identified major concepts become the reservoir from which the questions of the CoRe, such as "What do you intend the learners to know about this idea?" and "What concepts need to be taught before teaching this big idea?" can be answered. The CoRe serves in both the second and higher academic level courses as a tool to assess the development of TSPCK in the topic discussed explicitly in the intervention. It should be noticed that all five components of the TSPCK construct are included in the CoRe, thus providing us with insight on how pre-service teachers in the second year level courses develop understanding of the non-discussed components of TSPCK, namely, knowledge of what is potentially difficult to understand and conceptual teaching strategies. As discussed earlier, the methodology courses are the hub of our research activities due to the strong focus on developing TSPCK in core topics of science. In addition to developing a modified CoRe, the research team has also designed special tools that measure the quality of TSPCK in specific topics. Some of the topics used in the course have corresponding TSPCK tools available. These are mostly in the chemistry discipline, and include the following topics: chemical bonding, chemical equilibrium, organic chemistry, particulate nature of matter, stoichiometry and electrochemistry (Rollnick & Mavhunga, 2014). Two tools also exist for the physics discipline; electric circuits and kinematics. Such topics, where tools exist, allow us to assess the second outcome of the methodology courses, which is the transfer of the learnt knowledge about how to transform content knowledge using the components of TSPCK to engage with a new topic not discussed in class, and therefore develop TSPCK in the new topic. The mini-research reports from the 4th year class also serve as a major assessment, evaluating both the transfer of the competence to transform pedagogical knowledge in a new topic and the recognition of TSPCK in action by pre-service teachers.

We have also developed a five-point scale rubric of TSPCK to use in marking the completed TSPCK tools (see Table 3 below). The rubric is criterion based, developed to have four different categories that reflect the degree to which a response engages with the test question. The categories are 'Limited' assigned a score of 1, 'Basic' a score of 2, 'Developing' a score of 3 and 'Exemplary' having a score of 4, similar in structure to the rubric for measuring the quality of PCK by Park, Chen and Jung (2011). The category *Limited* reflects poor TSPCK, where none of the five components of TSPCK are adequately recognized in the pre-service teacher's responses to teacher tasks. The category *Basic* reflects limited recognition of individual components in pre-service teachers' responses, with no evident interaction with other components. The category *Developing* reflects recognition of the five components in ways that reflect interaction of at least three components. The *Exemplary* category has criteria calling for rich interaction of more than three components in the responses. The recorded audio classroom teaching are often analysed through the identification of TSPCK Episodes using the definition established by Park and Chen (2012, p. 928), where an episode is identified as a "teaching segment that indicated the presence of two or more components" of TSPCK are used in an interactive manner.

CONCLUSION: STRENGTHS AND AREAS FOR IMPROVEMENT

We started the discussion in this chapter by outlining the role that ITE is expected to play in restoring and re-building the state of science education in South Africa. We are encouraged by the revised national policy of minimum requirements for teacher education (MRTEQ). This policy now embraces subject specialization and the learning of pedagogies that recognizes the value of PCK as unique knowledge that assists teachers to build the understanding of difficult concepts for student understanding. We are also aware that PCK is highly valued in the science education community as one of the professional knowledge bases to be developed in ITE, although its implementation is still ongoing. Ball and

Table 3. A rubric to assess the completed TSPCK tools

	(1) Limited	*(2) Basic*	*(3) Developing*	*(4) Exemplary*
Learner Prior Knowledge	• No identification/No acknowledgement/ No consideration of student prior knowledge or misconceptions. • No attempt to address the misconception.	• Identifies misconception or prior knowledge. • Provides standardized definition as a means to counteract the misconception. • No drawing on other components.	• Identifies misconception or prior knowledge. • Provides standardized knowledge as definition. • Expands and re-phrase explanation using one other component of TSPCK interactively.	• Identifies misconception or prior knowledge. • Provides standardized knowledge as definition. • Expands and re-phrases explanation correctly. • Confronts misconceptions/ confirms accurate understanding drawing on two or more other component of TSPCK interactively.
Curriculum Saliency	• Identified concepts are a mix of Big Ideas and subordinate ideas. • Identified pre-concepts are far from topic. • Sequencing no value due to mixed concepts. • Reasons given are generic – benefit of education.	• Identifies at least 3 Big Ideas. • Not all 3 Big ideas subordinate concepts identified. • Suggested sequencing has one or two illogical placing of Big Ideas. • Identified pre-concepts are far from the current topic. • Reasons exclude conceptual considerations and show no evidence of drawing on other components.	• Identifies at least 3 Big Ideas. • Subordinate concepts correctly identified for all Big Ideas. • Provides logical sequence. • Identifies pre-concepts relevant to the topic. • Reasons given for importance of topic include reference to conceptual scaffolding/ sequential development draw on one other TSPCK components e.g. what makes topic difficult.	• Identifies at least 3 Big Ideas. • Subordinate concepts correctly identified for all Big Ideas with explanatory notes. • Provides logical sequence of all three Big Ideas and with logical reasons. • Identifies pre-concepts relevant to the current topic and explanatory notes given. • Reasons include conceptual scaffolding with reference to other TSPCK components.

(Continued)

Figure 3. (Continued)

	(1) Limited	*(2) Basic*	*(3) Developing*	*(4) Exemplary*
What makes topic difficult	• Identifies broad topics without reasons and specifying the actual sub-concepts that are problematic.	• Identifies specific concepts but provides broad generic reasons such as ‘abstract’.	• Identifies specific concepts leading to learner difficulty. • Reasons given relate to one other TSPCK components.	• Identifies specific concepts with reasons linking to specific gate-keeping concepts and to TSPCK components such as prior knowledge and aspects of curricular saliency.
Represen-tations	• Limited to use of only macroscopic (analogies, demos, etc.) representation with no explanation of specific links to the concepts represented.	• Use of macroscopic representation (analogies, demos, etc.) and use of scientific symbolic representation without explanatory notes to make the links to the aspects of the concept being explained.	• Use of macroscopic representation and use of scientific symbolic representation with explanatory notes linking the two representations to the aspect(s) of the concept being explained. • Use of above representations combined with reference to one other TSPCK components e.g. learner prior knowledge.	• Use of macroscopic representation or symbolic representation with sub-microscopic representation to enforce a specific aspect. • Explicit link to other components of TSPCK e.g./emphasis of core aspect of CK demonstrated in the representations and learner prior knowledge.
Teaching Strategies	• No evidence of acknowledgement of student prior knowledge and misconceptions. • Lacks aspects of curriculum saliency. • Use of representa-tions limited to mac-roscopic or symbolic representation.	• Acknowledges student misconceptions verbally with no corresponding confrontation strategy. • Lacks aspects of curriculum saliency. • Use of macroscopic and symbolic representations with no linking explanatory notes.	• Considers student prior knowledge and/or misconceptions. • Considers at least one aspect related to curriculum saliency e.g. sequencing or what not to discuss yet or emphasis on important concepts. • Uses at least two different levels of representations to enforce understanding.	• Considers student prior knowledge and evidence of confrontation of misconceptions. • Considers at least two aspects related to curriculum saliency: sequencing, what not to discuss yet, emphasis of important aspects. • Uses either the macroscopic or symbolic representation with sub-microscopic representation to enforce understanding.

Forzani (2009) remind us that the practice of teaching is not a natural process, but a purposefully constructed process. The strong focus on PCK found in our methodology courses, particularly PCK in specific topics (TSPCK) is a strength in two major ways. Firstly, from an educator perspective, it has provided a vehicle for fulfilling both the requirements for national imperatives as a well as a hub to explore models for implementation of the construct in ITE, an aspect of interest to the PCK literature. Secondly, pre-service teachers are being granted an opportunity to develop both their content knowledge and the knowledge of teaching (Mavhunga, 2014) in core topics, which in turn makes their learning of the teacher professional knowledge explicit to them. Van Driel and Berry (2012) argue for the importance of awareness by pre-service teachers of the knowledge they need in developing their practice. Analysis of the end-of-year general course reviews, not discussed in this chapter, indicate appreciation by the pre-service teachers of the language they have developed in talking about and describing their professional knowledge.

As most of the work being done with TSPCK in the courses is at the level of planning, the kind of TSPCK being developed is espoused or planned TSPCK. This means the pre-service teachers develop the skills of planning lessons that have sound big ideas, are pedagogically sequenced, and formulate explanations of concepts that draw interactively on multiple components of TSPCK to ensure accessibility by learners. However, for various reasons, including time constraints within the methodology courses, pre-service teachers have limited exposure to real classroom practice and would benefit from more enhanced in-school teaching during the course of their study. Hence, the extent to which the planned TSPCK in the various core topics is translated to enacted TSPCK is unknown. This is an area to focus on for improvement in our programmes.

In an effort to address this challenge, at the final year of study (the fourth year), pre-service teachers are exposed to a minimum level of research. They are asked to regard their allocated teaching during the school experience as a research project. In their final year, pre-service teachers are allocated 3 weeks of school exposure in the subject of their major choice. During this time, they are allocated a school where they will work under the academic mentorship of a practicing teacher in the school. They may be assigned by their allocated school to teach one or several classes in the last three grades of school, and they are likely to teach topics that may not have been covered in the methodology class for the final year. For the research element, they need to demonstrate evidence of planning and teaching that has considered transformation of content in the topic they are teaching. Therefore, the research element encourages them to return to the TSPCK framework and try to plan and enact their newly constructed TSPCK. Pre-service teachers are encouraged to formulate research questions of their choice as long as it is linked to their own teaching and has a TSPCK element in it. They are directed to consider lesson plans and audio recordings of their teaching as data.

Back on campus, after completion of the school teaching experience, they analyse their collected data for TSPCK episodes. Eventually, they develop research reports and a poster for presentation in a school of education undergraduate symposium where all other pre-service teachers from different disciplines present their projects. While detailed analysis of this approach is still under way, preliminary results based on pre-service teachers' self-analysis indicate an encouraging level of awareness of strengths and weaknesses in their own teaching. Also, pre-service teachers have developed the skill of articulating challenges generally encountered in classroom practice.

While we are encouraged by the findings and the potential demonstrated in developing pre-service teachers who have TSPCK in selected core topics and an understanding of the pedagogical transformation process, we encourage open discourse in the literature on what should be regarded as knowledge for teaching science and the models for implementation at different stages of the teacher qualification degree. Towards this end we offer our approaches as a stimulus for further exploration of the implementation of PCK in the form of TSPCK.

NOTE

[1] R is used to refer to "reception year", derived from practice in the United Kingdom. In the USA it is referred to as Kindergarten.

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KEITH POSTLETHWAITE AND NIGEL SKINNER

10. EDUCATING NEW SECONDARY SCHOOL PHYSICS TEACHERS

The University of Exeter Approach

INTRODUCTION

The National Context

In terms of *structure*, initial teacher education (ITE) in England is complex. Most new teachers who intend to work in the secondary sector (teaching 11–18 year old students) have obtained a first degree in their specialist subject or a closely aligned subject. They then follow a one year Postgraduate Certificate of Education (PGCE) course which provides insight into educational theory, into the range of effective ways of teaching key concepts in their subject, into non-subject-specific aspects of the role of the teacher, and into educational systems and current government initiatives in education. These courses are provider-based for 12 weeks, and school-based for 24 weeks. They are assessed through assignments usually leading to the award of masters-level credits, and through the analysis of evidence which the students collect to show that they have met the standards required of teachers (Department for Education, 2011) and can therefore be awarded Qualified Teacher Status (QTS). Some students follow a Professional Graduate Certificate in Education course which provides similar training, but with undergraduate (level 6) assessment rather than Masters level assessment. Some follow a QTS-only route in which evidence that they have met the teachers' standards is the only requirement. Traditionally, most PGCE courses have been provided by Universities working in partnership with schools, though in recent years governments have sought to train more teachers through school-based routes in which schools hold the power (though they often work in partnership with universities to ensure that their courses are academically rigorous).

The national context for ITE is also complex at the level of *principle*. Particularly since the 1980s, these principles have been contested (Furlong, Barton, Miles, Whiting, & Whitty, 2000). Whilst providers of teacher education programmes and successive governments have shared a desire to recruit the very best applicants and to train them to be highly successful teachers, the ways that providers, educational researchers and government policy makers conceptualise 'the best applicants' and 'successful teaching' are not always closely aligned. For example, government

A. J. Sickel & S. B. Witzig (Eds.), Designing and Teaching the Secondary Science Methods Course, 171–187.

policy has recently emphasised subject knowledge as a key criterion for the quality of applicants, and consequently have rewarded top graduates with generous training bursaries in subjects where there is a shortage of teacher supply (including physics). However, research has suggested that beyond a relatively modest threshold, increased subject knowledge may do little to improve teacher performance (see, for example Darling Hammond, 2000). Similarly, government policies have viewed 'successful teaching' as teaching which uses, for *all* pupils, well understood, commonly agreed 'best practice', whereas providers (especially in universities) have stressed that successful teaching is based on theoretically informed, context sensitive decision-making, through which, on the basis of complex and changing information, teachers choose the best practice for *their* pupils, in *their* context, at a specific time (Postlethwaite & Haggarty, 2012). It may be that these differences in perspective stem from different understandings of the nature of education itself. On the one hand education is seen as the technical delivery of pre-determined objectives made possible by the application of predetermined teaching skills; on the other, education is seen as the exploration of knowledge made possible by effective relationships between pupils and their teachers. Such education is inevitable risky (Biesta, 2014), where objectives change as the exploration unfolds (Kaptelinin & Nardi, 2006) and where the best outcomes may be achieved when neither the pupil nor the teacher knows what those outcomes will be at the beginning of the journey (Rancière, 1987).

These different principles are challenging for ITE providers and governments as there is significant risk of an unproductive tension in what is an essential relationship between the two. This risk is increased by that fact that the work of ITE providers is overseen by the Office for Standards in Education, Children's Services and Skills (OfSTED) – a non-ministerial government department which inspects ITE provision as well as schools and children's services. These inspections are 'high stakes' events for providers since a poor inspection outcome can result in a reduction in the number of trainees a provider can accept and, ultimately, in the closure of a course. In such a context there is pressure to conform to the 'official' view. However, at Exeter, we take a socio-cultural view of learning to teach which, as well as informing details of our practice, helps us to navigate this challenging territory in an optimistic frame of mind. Through the lens of activity theory (Kaptelinin & Nardi, 2006; Engestrom, Miettinen, & Punamaki-Gitai, 1999) we see governance of education as one activity system, and university-based teacher education as another. Each is shaped by the dispositions and histories of the people involved, by the tools at their disposal, by the motives that drive their actions, by the power structures within their systems, by the influences of the broader community with which they interact and by the rules which apply to their actions. Since the political system and university system are different in many aspects of each of these influences, it is to be expected that there will be tensions and contradictions between these systems as well as within each system. A powerful notion in activity theory is that such tensions are points for creative growth. One of our roles as an ITE provider is therefore to explore in depth both activity systems, to exploit the synergies between them, and to find creative solutions to the challenges that enable us to avoid the destructive effects of dismissing either point of view entirely.

Our Local Context

The University of Exeter is a successful, research-intensive university, which is enjoying a sustained period of growth and improvement. It is currently 93rd in the *Times Higher Education* table of world university rankings and 34th in the world in the Leiden Ranking of the scientific impact of universities and on universities' involvement in scientific collaboration. The Graduate School of Education (GSE) within this University is a strong provider of initial teacher education at primary and secondary levels and has been training teachers for many years. Over the past 3 years we have trained some 890 secondary teachers including 139 science specialists, of whom 20 were physicists. Our ITE programmes are closely informed by research – our own, and that of the educational research community generally. We take great care to work with teachers to sustain and develop an effective university/school partnership in the south west of England. This region is largely rural. There are areas of prosperity and growth, but also areas of significant rural deprivation, partly resulting from decline in traditional industries such as fishing and mining. Economically, the region is now very dependent on service industries such as tourism.

PLANNING

Course Structure

All our teacher education students spend most of the Autumn Term in Exeter, and then two terms in two schools (one term in each). This sequential course structure is partly dictated by the large geographical area in which our partner schools are based – which makes it logistically impossible for students to work in a concurrent structure, spending some days in each week in the university and some in school. We also adopt a sequential structure for pedagogic reasons. By basing the first term largely in the university, we can introduce students to a range of educational theory and practice, and ensure that they understand the theoretically grounded, carefully graduated, well supported, properly resourced approach to learning to teach which is the foundation of our provision (for details see Skinner, 2010). This approach avoids the problems associated with a 'sink or swim' model in which students are quickly immersed in school practice, may struggle to meet the demands of teaching in their initial contacts with classes, and may never recover their confidence.

Students have a graduated introduction to teaching, first observing lessons, then teaching short 'episodes' within the normal class teacher's lesson, then whole lessons and sequences of lessons. Our model also ensures that students have continuity of contact with all their classes, can immerse themselves in the culture of their schools and develop a good understanding of why a particular school has adopted its particular approach to teaching and learning.

Students teach across the full range of ages (11–18) and abilities attending their schools and are supported by the usual teachers of the classes which they are timetabled to teach, by a 'principal subject tutor' (PST) – a subject teacher at school who will provide detailed guidance about teaching their subject – and by a mentor who will be a teacher from a different subject specialism who will take a broader view of their learning. They are also visited by a university tutor in each placement. Assessment of this school-based work is carried out by the mentor and PST in discussion with the university visiting tutor.

Drawing on Activity Theory, we have developed tools to address the danger that this model will lead to students overlooking the essential connections between their school experience and their university experience. These can be conceptualised as 'boundary crossing' tools, since they are intended to enable students to make links between the topics that they have covered in the university and the actual practice of teaching as they encounter it in their school placements. Tensions or contradictions that exist between the guidance provided by the university and that provided in the school become points for discussion that can lead to creative resolutions and improvements in practice. Three of these tools are outlined below.

Our *Framework for Dialogue about Teaching* encourages students to use a socio-cultural perspective to interrogate issues in the practice that they observe, and in their own practice. It specifically requires that they consider the influence of theory and research on that issue, and explore how these theoretical insights combine with underlying values, with relevant aspects of national education policy, and with the characteristics of the particular school to guide the decision making that has shaped practice.

To view the Framework for Dialogue about Teaching, see: http://socialsciences.exeter.ac.uk/education/partnership/theexetermodelofite/frameworkfordialogueaboutteaching/

The *agenda* is a tool which students use to explore and develop an aspect of their own teaching. An agenda may be focussed on an issue such as the management of questioning in a particular class, or may relate to an issue across a number of classes, e.g. how to organise differentiated progression for a given class over a short sequence of lessons. Whenever appropriate, Agendas should be informed by research and theory.

To view a full description of the agenda tool, see: http://socialsciences.exeter.ac.uk/education/partnership/theexetermodelofite/agendasandevaluation/

The other tool is the *academic assessment* of the course. All students, whatever their subject specialism, take a common 'Education and Professional Studies' (EPS) module addressing classroom issues and their relationship to educational theory and research in a non-subject specific way, e.g. they study theories of learning and motivation, key concepts such as the notion of ability, whole school issues, and the role of education in the wider society. Students also take a 'Subject Knowledge and Pedagogy' module which, in relation to their own subject specialism, addresses issues of curriculum, subject pedagogy, subject knowledge and assessment, and makes specific links to the general EPS themes.

Both modules are assessed against the University's generic Masters level criteria. For their science specific module, students write a 6000-word report describing their design and critical analysis of a short scheme of work in science. Students describe the planned sequence of six lessons and provide a rationale for their design drawing on their subject knowledge, curriculum knowledge, knowledge of likely difficulties in teaching and learning this topic, and knowledge about pedagogy. They then choose one area such as differentiation or assessment and discuss in depth the relationship between the theoretical ideas from the Education and Professional Studies and Subject Knowledge and Pedagogy modules, their reading of the education research literature and the practical realities of the classroom. A formative assignment linked to this assessment provides opportunities for peer, tutor and self assessment and thus models a 'triple impact marking' approach often used in schools. This assessment, written in the Autumn Term, encourages them to think ahead to the possible links between theoretical ideas and classroom practice.

The EPS assessment, written while they are teaching in school, is a 6000-word report on a piece of action research that the students conduct in order to improve an aspect of their own teaching in their specialist area. In common with all quality action research, a student's project must show evidence of reconnaissance around the topic that will draw on relevant literature (including, for our science students, science education literature) and on detailed understanding of their school context. The actions that they design must also be informed by research, theory and contextual understanding. Therefore, in this assessment, students describe and evaluate the actual working links they have made between theory and practice in their attempt to improve their own teaching.

The structure of the Physics Subject Knowledge and Pedagogy Module The Physics Subject Knowledge and Pedagogy module contains the components set out below.

- A series of *science education lectures* developing, in the science context, ideas about such topics as learning, motivation, special educational needs and assessment that have been introduced in the EPS module. These lectures also address other general issues in science education such as different ideas about the nature of science, the role of practical work and fieldwork in science, the use of ICT in science teaching, and health and safety issues in the school science laboratory. Students in other secondary science specialisms study this same set of lectures.
- A series of eight *lab-based physics workshops* which explore ways of teaching key physics topics to pupils in the 11–18 age range. They provide support for students in filling gaps in their subject knowledge – though this is mainly a matter for private study on the part of the students, supported by a system of needs

analysis and review. More importantly, they provide insight into pedagogical content knowledge (Shulman, 1987) – the best sequencing of ideas, the best ways of explaining topics, the best demonstrations and practical tasks, the best models (and their limitations), the ways in which the mathematical and literacy demands of the topic are best addressed. They draw explicitly on theories of learning and on the research literature and thus make direct links with the science lectures and the EPS lectures. Physics specialists will also attend eight workshops in chemistry and eight in biology. These are similar in purpose and approach to the physics sessions but focus on teaching pupils in the 11–16 age range with the main emphasis being on 11–13 teaching.
- *Peer teaching*, in which students present short pieces of teaching to groups of fellow students. The teaching is designed for pupils in the early secondary years and the student audience provide feedback on how they think the teaching would be received by pupils in school. Students reflect on these experiences, and are given feedback by tutors. Each student's last piece of peer teaching is recorded on video so that they can review their teaching in detail.
- *Subject support groups*, in which students meet in their subject specialist groups. Each group reviews the subject knowledge strengths of its members and the areas in which members feel the need for some subject knowledge development. Each student then runs a 40 minute seminar for their peers in which they explain the topic in which they have particular expertise. These seminars differ from peer teaching sessions in that they are pitched at degree level. Students are asked to discuss their subject support teaching experience, and the feedback they will receive from their peers, with their tutor to explore what they have learnt from the task.
- *Special interest sessions* from visiting specialists and experienced teachers. The content of these sessions vary but have recently included sessions on earth science and astronomy. Physics students have also been invited to attend an annual conference for physics teachers run by the Institute of Physics, usually on the University campus. This always includes a keynote lecture from a leading physics researcher and a large number of workshops focussed on physics teaching.

These course components are designed to introduce students to the *range of possibilities* open to them as they teach physics rather than promoting one particular approach. We argue that this is essential, as our students will teach in a wide range of contexts throughout their careers and it is vital that they make informed decisions about their teaching methods while taking account of the details of their context as well as theories of science education. The components all involve *active engagement with learning*. This is clearly the case with the lab-based workshops (which give students opportunities to try out useful school practical tasks and to find the strengths and pitfalls of common school equipment) and of the peer teaching sessions (which give an opportunity to try out pedagogical ideas in a safe setting), but it is also true of lectures. To date, these lectures have exploited information technology to encourage students to revisit ideas, and link them to specific aspects of their own teaching (e.g. through their assignments and through involvement in online discussion forums). We are currently taking this further by 'flipping the classroom' so that information is shared online in advance and then discussed and debated in the lecture sessions. The components all involve *social learning* – the sharing of half formed ideas and alternative views so that personal decisions about teaching can be as widely informed as possible. There are therefore common threads running through all the components, but each component demonstrates these threads in a different way, with some components placing more emphasis than others on a particular thread.

The workshops for the physics students are designed to reflect the content of single subject physics General Certificate in Secondary Education (GCSE) courses. GCSE courses are subject specific courses usually taken by students in England during years 10 and 11 and which are assessed by examinations at the end of year 11. These examinations are set by national examination boards. There are eight, two hour physics workshops, all taught in a laboratory designed and equipped to match what students can expect to find in most schools. The laboratory is serviced by a science technician who prepares the large amount of equipment needed to address 5 years of secondary school teaching on a given topic in the 2 hour session. Although there is insufficient time to consider all GCSE topics in depth, the workshops address many of these and focus on 'threshold concepts' (Meyer & Land, 2003) which are fundamental in physics (particularly concepts related to forces and motion, current electricity and energy) and on topics where there are particular issues of safety such as radioactivity. We begin with two workshops on forces and motion, then two on electricity. We build on the electricity workshops by looking at electromagnetism, including the electric motor, the transformer and power transmission. We then address optics, particles and radioactivity, and energy. In each workshop we consider what pupils will have studied (in a largely concrete fashion) in primary school, discuss how this can be built on to develop more formal ways of thinking about the topics, and explore how the ideas can be developed as the pupils move from Year 7 (at the start of their secondary education) to Year 11 (the year of their GCSE examinations). We draw close attention to issues which pupils find challenging and how these can be addressed, making links to EPS and science lectures on learning theories – especially to constructivist (Driver & Oldham, 1986; Driver, Squires, Rushworth, & Wood-Robinson, 1994; Osborne & Freyberg, 1985; Watts & Jofili, 1998) and social constructivist (Hodson & Hodson, 1998) views of learning. We also consider how work can be differentiated for pupils of differing abilities (Postlethwaite, 1993), identify the mathematical demands of the topic (Orton & Roper, 2000), and explore how pupils can be supported to meet these demands. We consider how the physics teaching can support the development of pupils' skills in literacy in science (http://socialsciences.exeter.ac.uk/education/partnership/leadingpartners/) and we draw attention to safety issues in the activities that students may undertake with their pupils. A similar workshop structure is used in the physics workshops for biology and chemistry specialists, although the amount of content addressed is often slightly reduced to give more time for discussion of subject knowledge issues where these are relevant to a particular group.

For the specialist physicists, an additional element of the workshops relates to post-16 Advanced (A) level physics courses. Given the depth and volume of A-level content, it is challenging to provide insight into teaching at this level in the time available in the workshops. We address this in several ways. We take some of the topics in the GCSE-focussed sessions outlined above and consider how they are extended at A-level. One example is that we extend the session on electromagnetism by adding detailed quantitative study of forces on a current and forces on a moving charge. We use a fine beam tube (http://practicalphysics.org/fine-beam-tube.html) to study the circular motion of electrons in a magnetic field and measure e/m for the electron. We analyse the Hall effect to show how the forces on charges moving along a conductor as a current, can produce an electric field across that conductor, and use the same analysis to show how charges that are moving because they are in a wire that is moving, can produce an electric field in that wire – and thus we explain electromagnetic induction. We look at A-level examination questions on some key topics, developing marking schemes (grading criteria) and then comparing these with the official schemes. We also have a separate session that considers more general pedagogical issues in A-level teaching by considering ways in which mathematical modelling, practical demonstration, practical investigation, structured questioning, and teacher-led enquiry can be combined to support effective learning at this level.

There are many exciting ways to teach GCSE and A-level physics topics. These include ways to challenge 'common sense' explanations of phenomena, to avoid misunderstandings, and to stimulate pupils' curiosity and fascination with the physical world. Many valuable practical experiences can be used to enhance understanding such as pushing a balloon into water so that pupils really believe in the idea of upthrust from a liquid – a belief that can be explained later by discussion of pressure in the body of a liquid. There are useful models that pupils can use and critique e.g. a model of solids, liquids and gases that pupils can construct from their own bodies by arranging themselves in groups and moving in ways appropriate to each phase. There are useful analogies such as that between money and energy – the amount of each remains the same when they are transferred from one place to another, and it is in that transfer that useful things are done. (With this analogy it is important to stress that we need to take a common-sense view of money, not a sophisticated economist's view that allows for things such as quantitative easing!) Diagrams, charts and graphs can be used not mainly as summaries to be learnt, or artefacts to be constructed, but as tools that support understanding and prompt the raising of questions. There are opportunities to challenge well-established methods for teaching particular topics, a classic example being the need to overturn the ineffective standard treatment of energy in terms of transformation from one (so-called) form of energy to another and to replace it with a treatment based on transfer of energy from one place to another (Millar, 2005). The money analogy is useful again here, stressing that forms of money and energy are relatively unimportant; that both are conserved but tend to spread out and are then of little practical use; that it is transfers of each that are significant. In light of this richness, it is challenging to limit further discussion of the physics workshops to just one topic, but that is what we now do in order to illustrate in more detail the approach we take.

CLASSROOM PRACTICE: VIGNETTE OF AN ELECTRICITY WORKSHOP

The two-hour workshop on which we focus is the first of the two electricity workshops. A good starting point is discussion of why bulbs in parallel across a cell get dimmer as more bulbs are added. Partially discharged cells work best to demonstrate this to the students. This dimming is problematic for pupils early in their secondary education because we encourage them to argue that a parallel circuit is essentially two separate circuits connected to the same cell and sharing some bits of the wiring of the circuit(s). It follows that if the bulbs are identical, each will light to the same brightness as the current through each bulb will be the same, and adding the extra bulb should do nothing to affect how much current is pushed through the original bulb. In discussing amongst themselves, the puzzle that in practice the bulbs often *do* get dimmer, the graduate physicist students will draw on a wide range of concepts. It is then useful to pose the question, "What will you say to an 11 year old who is investigating parallel circuits, if they ask you to explain this phenomenon?" The point, of course, is that the pupils do not yet know many of the concepts used by the physics students to understand the observation. We cannot quickly fill all of these conceptual gaps to enable us to give a full explanation. Equally, saying "You'll learn about that later" is clearly inadequate. We have to respond differently. One approach is to avoid the problem by ensuring that cells are new, and that bulbs draw only small currents. The circuit then behaves as the simple description of parallel circuits we are lead to expect and the problem does not emerge. Another approach is to work with the concepts that the pupils *do* understand so that we can produce answers that are not false, but which are, admittedly, incomplete. We can then use the remaining gap in understanding to stimulate the pupils to explore the issue further – or to choose, for themselves, to leave the fuller explanation for later. For example, if pupils already understand the idea of energy transfer, we might encourage them to think that when an extra bulb is added to a *series* circuit, each bulb is dimmer as the energy carried round the circuit is now shared by the two bulbs. That might prompt us to speculate that in a *parallel* circuit there must be another energy transfer going on in addition to those taking place in the two bulbs. We might argue that the only other component in the circuit is the cell, so perhaps there's an energy transfer going on there. Having got that far, we might leave the fuller explanation of that internal energy transfer as a puzzle until notions of resistance, potential difference and Ohm's Law are secure.

This starting point for the workshop serves to demonstrate to physics graduates that they will need every bit of their expert knowledge of physics to teach 11 year old pupils, not because they need to know the mathematics of Maxwell's equations or the detailed implications of the discovery of the Higgs boson for particle physics, but because they will have to make scientifically challenging decisions about what works as an explanation of a physics experience for a class of pupils of that age, or for a particularly able pupil, or a particular pupil with learning difficulties, who is raising the issue with them. Physics teachers do not (usually) need to think about hard and deep physics: they need to be able to think hard and think deeply about simple physics – and that is just as demanding.

Having raised the issue of the web of concepts involved in teaching simple current electricity, it can be useful to construct a concept map of the topic with the group. As the workshop progresses we can return to the map, to extend, develop and correct parts of it as we tackle each issue. The map helps us to keep the whole picture in our heads as we work on parts of that picture. A similar tactic can be used by the students as they teach their pupils. The concept map serves as an 'advance organiser' (Ausubel & Robinson, 1969) which helps to orient the pupils in the field and thus promotes what Ausubel calls 'meaningful learning' – learning in which connections are appreciated and used. It can be particularly useful to holistic learners who may find the usual serial treatment of ideas in physics unappealing.

The workshop then moves on to practical tasks, which the students complete with simple series circuits – light a bulb with a cell; try the effects of different coloured wires; try changing the shape of the circuit; try the effect of adding a resistor, variable resistor, diode to the series circuit and try reversing each of these components; try adding more bulbs and more cells; replace the bulb by a short single strand of wire wool; place a plotting compass under the wire in a circuit, with the wire lying along the length of the compass needle and then switch on the circuit; connect the positive side of the cell to a carbon rod and the negative side to a silver coin and immerse both in a beaker of copper (II) sulfate; with two cells and two bulbs, measure the current at all points around the circuit (before the bulbs, between the bulbs, after the bulbs, and between the cells).

In discussion, we tease out that a complete circuit is needed, so maybe (just a speculation to be tested later) there is something flowing round that circuit. Let's call that an electric current – rather like a water current in a central heating system. We note that the colours of the wires and the shape of the circuit don't make a difference. If we don't give pupils a chance to test this, they may well carry forward misconceptions that there have to be red and black wires, and that circuits have to be neat with straight wires and right angle corners just like all the circuit diagrams in their books. We note that resistors reduce the current (like narrow bits of pipe); that a variable resistor provides continuous control of current (e.g. controlling the brightness of lights in a house or on stage, or the speed of motors, or the volume of a loudspeaker). We note that these components have the same effect whichever way round they are connected, but that the diode only allows current to flow one way. If pupils don't try reversing all components, they may well think, having discovered the effect of reversing the diode, that all components are one way devices.

The next group of tasks explores the properties of this current. The wire wool burns (often drawing 'oohs and aahs' even from cynical graduates!), indicating a heating effect. Links can then be made to bulbs and speculation can be encouraged about why the wire wool burns away but the bulb lights continuously. The compass needle deflects, indicating that the current produces a magnetic field. This is picked up and developed in the electromagnetism workshop. The coin in the copper (II) sulfate becomes coated with copper – a metal that was not present at the beginning. Something new has been formed – so the current has a chemical effect.

Students are then encouraged to discuss how they could use the heating effect, chemical effect and magnetic effect to measure current. They quickly decide that although all effects *could* be used (see, for example, http://practicalphysics.org/model-hot-wire-ammeter.html), the heating and chemical effects pose significant practical difficulties if responsive and accurate measurements are to be obtained. A simple demonstration of a moving iron "drinking straw ammeter" (Nuffield Physics, 1967a, p. 24) shows how the magnetic effect of a current provides a realistic way of measuring current. Once this is clear, it is relatively easy to show how commercial ammeters use the same principle, albeit in a physically more robust arrangement.

At this point a brief detour into mathematics and physics is relevant, as reading ammeter scales is problematic for some pupils. Building on some of our own research with secondary pupils, we use the idea that most pupils work out scale readings by 'guess and check' – they guess what the minor divisions of the scale mean, then check to see if this guess is consistent with the major divisions. Good scale readers simply revise their guess if this check shows inconsistency; poor scale readers give up. A good way to support pupils is therefore to encourage them to carry on with the technique that they already use, be willing to try alternative guesses and have confidence that after a few (informed) guesses they will come up with a solution. For pupils who still find scale reading difficult, a digital ammeter may offer a solution though this brings the problem that readings usually fluctuate and pupils may need help in dealing with this.

We now turn to a demonstration that is an excellent way of gaining insight into what an electrical current actually is. It involves a table tennis ball that is coated in colloidal graphite (Aquadag) to make it conducting, and suspended on a cotton thread between two metal plates (Nuffield Physics, 1967b, p. 332). The plates are connected to a 5kV power supply. When we touch the ball on to one plate, the ball will bounce continually between the two plates. Students can explain this in terms of the ball becoming charged when it touches a plate, being repelled from that plate because the ball and the plate have the same sign of charge, crossing the gap, touching the other plate, charging again – this time with the same sign charge as is on that second plate, therefore being repelled from that second plate – and so on. They can easily identify that charge is being carried across the gap. If a sensitive (light spot) galvanometer is included in this circuit (on the earthed side of the power supply to avoid sparks inside the galvanometer), the galvo indicates that a current is flowing. This current increases if the ball is made to bounce more quickly, and stops if the ball is stopped. Since there is a current all the way around the simple series circuit – including between the plates where we know there to be moving charge – there is a strong indication that current and moving charge are one and the same thing. This can be reinforced by arranging students (or their pupils) in a complete circle, giving each a small dish, explaining that these dishes represent charge and then exploring what will happen if one of the 'charges' is handed on to the next person. Because the 'charges' repel, that next person will pass on their 'charge' as the one they are being given approaches. As a result, the 'charges' begin to move round the circuit. It is nice to remove one student from the circle in which case the 'current' stops everywhere – just like an electrical circuit where a connection is broken.

At this point, with a growing understanding of the nature and properties of a current, we turn to the result of the final task from the list with which we started – the finding (that is unexpected for many pupils) that the current is the same all the way round a series circuit (even between the cells of the battery). This is often a very challenging result for them as they feel that they are 'getting something for nothing' when the bulb lights. Some resist the result on this common sense basis, some may formalise this by reference to energy conservation, some may complain that current conservation fails to explain why the battery goes flat, or to account for the fact that we have to pay for electricity from power stations – if they get back all the current they send us, what are we paying for?

To explore the best way to teach this issue, the workshop makes an explicit link to constructivist theories of learning that are introduced in an EPS lecture and followed up in the science context in a science lecture. We explore what the literature discussed in these lectures has to say on the subject of common misconceptions – but we do it in the context of thinking about current (Driver et al., 1994; Küçüközer & Kocakülah, 2007). The literature shows that pupils usually have one of the following models of current: a single terminal model in which current flows from battery to bulb, the return wire being a necessary part of the circuit but a part that usually doesn't do anything (rather like an earth wire in a mains circuit); a 'current completely used up' model (which is similar to the single terminal model); a 'current partially used up model' in which some current is used up to light the bulb but some has to return to the cell to make the circuit work; the 'clashing currents' model in which currents flow from both ends of the cell to meet in the bulb and cause it to light; and the formal 'current conserved' model. We explore where these models come from. For example, the single terminal model may be the result of looking at the inside of a simple torch, where the bulb appears to sit on the stack of cells touching the positive terminal of the top cell. The fact that the body of the torch forms the return path is easily overlooked. An intriguing model is the 'clashing currents' model – this was the model initially adopted by Ampère, so is not one to dismiss too readily.

We discuss eliciting these models from the pupils in a particular class by setting questions that prompt them to describe what they think is happening in a circuit. Alternatively, we may elicit their thinking through class discussion, perhaps supported by earlier group discussion of relevant concept cartoons (Naylor & Keogh, 2000). We then discuss the use of the experimental evidence that ammeters do read the same on both sides of a bulb as a 'cognitive conflict' (Nussbaum & Novick, 1982). This challenges the single terminal and 'current used up' models. This is an important piece of evidence, but we go on to explore the possibility that some pupils may fail fully to accept its consequences on the grounds that 'you can't get something for nothing, so current conservation must be wrong'. Some of these pupils will interpret tiny differences in ammeter readings as evidence that some current is used up; some will learn that they have to say that current is conserved when talking to the teacher or answering an exam question, but will not change their personal model of what is happening. This leads us to consider in more detail what is happening.

We discuss that as charge moves through the cell, energy is loaded on to the charge and carried round the circuit. When the charge passes through the bulb, the energy is transferred to the bulb and out into the room as heat and light. The charge goes on round to pick up another load of energy. We model this by repeating the 'pupil model' described above but this time one person acts as the battery and is given a small supply of polystyrene balls, each of which represents some energy that was stored in the cell. Their job is to place one ball in each dish as it passes them. Another person acts as the bulb – when the loaded dish reaches them they throw the ball out into the room and then pass the dish on. Current is conserved, energy is transferred from battery to bulb to room, and the battery goes flat because its store of energy is depleted. We no longer seem to be getting something for nothing – and the current conservation model is much more likely to be accepted.

It is important to note that challenging the clashing current model experimentally is difficult, so it is helpful here to point out that, in wires, there are no free positive particles that can flow from the positive terminal of the cell, so there is no mechanism through which the model can work. It is, of course, different if the current is flowing in a liquid containing positive and negative ions, so if we dismiss this model too easily we may build up problems when pupils consider electrochemistry later in their science education.

Throughout this set of activities, and all the other workshops, we model different ways in which students could teach their own lessons in future classrooms. There is a lot of discussion, practical work by students, practical demonstrations, use of teaching aids such as the interactive whiteboard and relevant 'YouTube' videos. There is a lot of to-and-fro between physics content and the effective teaching of that content. There is a lot of encouragement for students to answer very challenging questions about very simple physics – a skill which physics teachers (perhaps uniquely amongst professional physicists) need. Our teaching, exemplified above, is consistent with the three themes for the whole module that were identified earlier: namely, demonstrating the range of possible ways of teaching a topic, the value of active engagement of students in learning, and the value of social learning. As the workshops progress, we continually consider how the ideas and approaches used could inform the students' own teaching – that, after all, is the main purpose of developing their pedagogical content knowledge in these sessions.

STUDENT ASSESSMENT: VIGNETTE OF STUDENT ACTION RESEARCH

The Education and Professional Studies assignment is a small-scale, enquiry-based research project conducted in the student's first school placement. It is designed to draw together all the different elements of their teaching and training experiences through focusing on an aspect of the teaching and learning of science that they wish to investigate and improve. It is marked against the University's standard masters level criteria which identify what is required for a pass, a merit, or a distinction in relation to the student's knowledge of the topic, cognitive skills (e.g. of critical analysis, and logical argument), research skills (including use of research-informed literature) and skills for life and professional employment.

Students begin thinking about a focus for their assignment and discussing this with a university tutor in the autumn term. During the first few weeks of their placement they continue this 'reconnaissance' phase of action research through background reading and discussions with the science teachers they are working most closely with in school. We find that trainees often benefit most when the research focus builds on targets which emerge from their school-based 'Weekly Subject Development Meetings'. Examples of the kinds of topics that students might choose to explore are: how to improve the effectiveness of pupils' use of physics textbooks; how to identify and modify pupils' initial ideas about energy; how to improve pupils' accuracy in reading instrument scales by using IT simulations.

When they have been in their placement school for 4 weeks the students submit a research plan for their project to a university tutor who then provides detailed formative feedback on the plan. The plan is framed using a series of questions concerning the clarity and context of their focus, their reasons for choosing it and ways in which it relates to their practice. When a clear focus on a topic in which the students have clear agency for action has been agreed upon, feedback is provided on potential research tools and methods for collecting and analysing data. A key issue here is to ensure that their study is not too ambitious since students only have eight weeks to complete and submit the assignment.

The reporting of the assignment follows the typical format of a journal article, comprising abstract, introduction, literature review, methodology, findings, discussion and conclusions sections. One of the difficulties that our science students (particularly those with a physical science background) encounter when writing this stems from their training in the approaches to research used in natural sciences and the contrasting methodological approaches that are used in social science. EPS sessions, which focus on approaches used in social science research, are provided to address this concern and optional sessions on 'writing at Masters level' are also available.

As noted above, this assessment is designed to help our students describe and evaluate the links between educational theory and practice that they make in an attempt to improve their teaching. It brings together the university based component of our programme, which introduces students to the kinds of knowledge that are valued by academic communities (often referred to as 'codified' or 'public' knowledge about teaching and learning that is generalised and generalizable), with the 'personal' professional craft knowledge of experienced science teachers.

Hagger and McIntyre (2006) argue for "the importance of planned structures to facilitate all the many different potentially helpful kinds of workplace learning" (p. 51). The value of helping students to make links between theory and practice using the planned structure of this assignment is evident from a study of Exeter-based student science teachers following the programme described above. In an interview probing the value of the different assessment components of the course, one student said:

> I found that the second one [action research] especially was fantastically helpful for me. It was interesting, I loved doing it. I did the misconceptions of pupils' understanding of sound and light, and having the books and lecture notes, and the lectures on misconception as well, to see how kids formulate these ideas early on in life – it was really interesting to do it. (Skinner, 2010, p. 287)

CONCLUSION

Kurt Lewin, a leading voice in the early development of action research, is well known for arguing that "There is nothing as practical as a good theory." (in Tolman, Cherry, van Hezevijk, & Lubek, 1996, p. 31) We are confident that our course is successful in demonstrating that educational theory is a major resource for teachers. Sociocultural theory has shaped the basic principles of the course and a range of pedagogical theory has informed our science workshops. The vignettes above show that we help students to see how these theories can alert them to possible obstacles to pupil learning, how to get over them and how to develop practical ideas for their lessons that can enable them to make effective provisions for particular pupils in a particular school context. Our course tools – the framework for dialogue, agendas and the academic assessment – support them in making the links between theory and practice.

Issues which still exercise us are how to make provisions that are more effectively differentiated to meet the needs of students with very different academic backgrounds (for example first degrees in a range of physics-related subjects), very different science-related work experience, and different kinds of experiences with communicating science to young people. A goal is to address these issues through best practice in pedagogical differentiation, in ways which model what students can expect to do in their own practice as teachers. Given the lack of cultural diversity in the region (and therefore in its schools), a particularly challenging aspect of this issue is to help students to provide for the cultural differences which they do encounter. As part of this, painting a picture of science as a worldwide enterprise is essential.

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11. METHODS FOR PHYSICS TEACHERS

A Case in South Korea

INTRODUCTION: CONTEXT

The methods course described in this chapter is situated in the secondary physics teacher licensure process in South Korea. The context of the teacher preparation program is described, followed by features of the course participants. Then descriptions of course design, implementation and assessment are presented.

Standards for Secondary Subject Teacher Licensure

The Korean Ministry of Education has standardized teacher preparation programs to ensure the quality of new teachers. The government approves of teacher education programs at the undergraduate or graduate level nationwide. Currently, there are colleges of education or teacher licensure programs in 16 national and 29 private universities approved for undergraduate licensure. For secondary science teacher preparation, each college has subject specific programs such as physics education, biology education, chemistry education, and earth science education. Not all colleges of education have all four science-education majors. As for physics teacher preparation, currently there are 14 undergraduate programs across the nation.[1] Upon successful completion of a program, all four science education majors are certified to teach middle school science and high school general science as well as a high school subject of their major (chemistry, physics, biology, or earth science).[2]

The Korean Ministry of Education regularly publishes a Handbook of Teacher License Approval that elaborates requirements for licensure and administrative procedures (Korean Ministry of Education, 2016). For initial licensure of secondary science teacher, currently 50 credits[3] in major courses and 22 credits in general education courses are required. To obtain a license, preservice teachers should get above a C median GPA in their major, and above a B median GPA in general education courses. Among the major courses, 21 credits should be taken from specific courses listed in the handbook. Of these, at least 8 credits in subject-specific pedagogy courses are required. A science or physics methods course is one of these courses. Most physics teacher education programs in South Korea offer a 3-credit methods course, typically named "Theory of science/physics education." In addition to this, typical subject-specific pedagogy courses include physics teaching materials,

A. J. Sickel & S. B. Witzig (Eds.), Designing and Teaching the Secondary Science Methods Course, 189–206.

logic and essay writing in physics and school physics experiments. These courses are usually worth 3 credits each.

Influence of National Teacher Employment Examination

The content of courses in general education and content areas are closely related to the National Teacher Employment Examination (NTEE) that is yearly offered by the government. Public school teachers are employed on the basis of this exam, while private schools use their own system (Kang & Hong, 2008). The NTEE has two rounds. The first is a paper and pencil test, and the second is demonstration of teaching and interviews.[4] In the paper-and-pencil test, 20 points are allocated to general education questions and 80 points are allocated to content, of which about 25 points address content specific to physics methods courses. Thus, the methods course is important for preservice physics teachers not only for its practical value but also for preparation for the exam.

The exam questions are developed by teacher education professors in each subject. Thus, the course content is directly related to what is tested on NTEE. In research on physics methods content tested on the exam administered over five years, between 2008 and 2012 (Kang & Lee, 2013), the following content distribution of exam questions were found.

Table 1. Subject specific pedagogical knowledge tested

Elements	*Percentage of test questions (%)*
Knowledge about the nature of physics (history and philosophy of physics) and inquiry	33
Knowledge of teaching including instructional models, learning theories, and teaching strategies	30
Knowledge of curriculum	17
Knowledge of learner including student prior knowledge, learning difficulties and interests	15
Knowledge of assessment	5

Students and the Course

The methods course described in this chapter is offered in an undergraduate level physics teacher education program that is a four-year (8 semesters) program[5] and has on average 20 physics education majors as a cohort. The preservice physics teachers in the course applied for the program upon entrance of college.[6] Thus, most of them are those who decided to be physics teachers upon college entrance. As the first physics education course, the methods course is offered in the fifth semester, and the preservice teachers have their first four-week full time teaching practicum in the following semester. Thus, the methods course is instrumental for preparing the preservice teachers for their first practicum. The physics education program in this specific university requires two four-week full time[7] teaching practica. The second one is required in the seventh semester. Because they are licensed to teach both in middle and high school, they are in general assigned to middle and high schools each time.

Before the methods course, the preservice teachers have been taking general education courses such as educational psychology, classroom management and so on as teacher licensure requires 20 credits of general education courses over four years while 9-credit physics education courses are required for licensure in addition to physics content courses.

After the methods course, the preservice teachers take a 3-credit Physics Reasoning and Writing (PRW) course during the sixth semester, and then a 3-credit Physics Teaching Materials (PTM) course. The PRW course is designated by the Korean Ministry of Education as required for licensure. The course addresses scientific thinking and writing based on inductive, deductive, abductive and hypothetico-deductive reasoning along with teaching methods in scientific writing. The PTM course addresses the national curriculum and developing teaching materials for secondary physics classes in connection to instructional models and strategies. Upon completion of 9 credits of physics education courses, the preservice teachers meet the required credits in physics pedagogy for licensure.

PLANNING: DISCUSSION OF COURSE DESIGN

The methods course meets once a week for three hours over 17 weeks. By the time preservice teachers take the methods course, they have taken many general education courses (e.g., philosophy of education, educational psychology, assessment and measurement). They concurrently take physics content courses (electromagnetism, quantum mechanics). Yet they rarely have any experience of connecting pedagogy to physics content. Thus the focus of the course is helping them connect what they know in physics to pedagogy in a form they can directly apply to teaching during the practicum in the following semester.

The main goals of the course include developing (a) a professional vision that prioritizes student thinking as a resource in teaching and learning, (b) the ability to visualize physics or science teaching practices, and (c) teaching competencies. The physics methods course addresses the topics in Table 2.

Typically, these topics are addressed in the order listed in Table 2. These topics are addressed in the methods course because the author believes the content should be introduced to preservice teachers before entering the classroom in the following semester for the first practicum. Additionally, all the topics are tested in the teacher employment exam. The order of the topic is decided based on the reasoning that the preservice teachers should first understand students' prior knowledge in relation

Table 2. Topics addressed in the physics methods course

Theme	*Specific Topic*
Student Thinking (2 weeks)	History of science and its implication for science education Student naïve ideas
Learning Theories (3 week)	Models of science instruction: Conceptual change, generative learning model Discovery learning by Bruner, conceptual change by Piaget, social constructivist learning by Vygotsky
Science Curriculum (4 weeks)	Goals of science education and the curriculum emphasis Inquiry and process skills Scientific reasoning: inductive reasoning, deductive reasoning, hyothetico-deductive reasoning, abductive reasoning The nature of scientific knowledge and its development: K. Popper, T. S. Kuhn, I. Lakatos
Instructional Models and Strategies (1 week)	Learning cycle, analogy, cooperative learning, POE, role-play
Teaching demonstration (4~5 weeks)	Lesson planning: Ways to apply instructional strategies to teaching science/physics Practice of teaching
Science laboratory (1~2 weeks)	Science laboratory work, fieldwork and safety

to the historical development of scientific ideas. Discussion on student ideas is naturally linked to the conceptual change view of learning. This naturally leads to the discussion on various learning theories.

After the discussion on learning theories, the preservice teachers are introduced to the curriculum theories and a brief history of Korean national curriculum. This topic is considered to be important in understanding the current school science content and approaches to teaching. Along with the curriculum, science inquiry is addressed in depth because it has been emphasized in the national curriculum for a long time. Inquiry skills included in the national curriculum are first reviewed. Then scientific reasoning behind science inquiry and then philosophy of science are addressed. This leads to a discussion on how to teach. Instructional models and strategies are addressed. The discussion is repeatedly related back to learning theories. Then the preservice teachers individually demonstrate a short lesson in front of their peers in order to practice instructional strategies. After a teaching demonstration, practical issues related to science laboratory are addressed in light of preparation for practicum.

The decision on the scope and sequence of the course content is mainly based on the 15 years of science methods teaching experience of the author. However, certain topics such as the philosophy of science and some instructional models are addressed more than practical needs because they are tested on the teacher employment exam.

Typically, preservice teachers read the assigned reading material and post questions or discussion topics in a shared Cloud server prior to each three-hour class meeting. In class, they work in groups to discuss the readings, along with their posted questions or discussion topics and complete class tasks by utilizing the content. All group conclusions are presented in class and some of them are posted in the Cloud.

Developing Habits of Mind Centred on Student Thinking

The goal of developing habits of mind that focuses on student ideas in teaching is the first priority in the course. This would help them develop a disposition of making science lessons student centred. For this purpose, a number of topics including student prior ideas, learning theories, instructional models and strategies based on conceptual change pedagogy are addressed (Kang, 2007).

Student prior knowledge. First and foremost, preservice teachers must realize the role of student thinking in learning and research findings of common student concepts in major topics. For this, the history of science and its implications for science education is addressed.

The textbook for the course provides good resources that well summarize the historical development of ideas about force and motion, atoms of matter, heat and temperature, life and biological processes, and the shape of earth, all topics addressed in school science. A great deal of research on student prior knowledge about these topics is also available in the literature (IPN, 2009), and some of them are presented in the textbook in relation to the historical development of scientific concepts.

The historical development of scientific ideas is relatively new to preservice teachers. The learning of this subject is justified and emphasized with an introduction to the similarity between students' naïve ideas and historical ideas in science (e.g., Eckstein, 1997; Wandersee, 1986). The topic is well accepted during class discussion as the preservice teachers find their own prior ideas have been or are similar to those reported in the text.

The amount of content about the historical development of scientific ideas, though essential, is too much to deal with one by one given the time for the course. Also, the content is not too difficult for the preservice teachers to understand on their own. Thus the topic is taught in a jigsaw method. In doing so, the jigsaw method (Aronson & Patnoe, 2011) is introduced to the preservice teachers as a way to address a lot of content simultaneously in a learner-centred way. The preservice teachers are divided into groups based on the topics that they want to study and they teach each other as experts on the topic of their choice. Before each group undertake studying their topics, I provide guidance on what to focus on as I give out reading materials. This approach is well received.

After the discussion on the historical development of scientific concepts and relevant student prior knowledge, each group of the preservice teachers is required to find a counterintuitive phenomenon that can engage students in productive discussions on the phenomenon trying to create an explanation (Chinn & Brewer, 1998). This provides resources for their later activities for the course.

After these series of activities, the preservice teachers are asked to reflect on their learning in writing. The reflection is very informal and has a prompt, "We have studied the parallel between ideas in the history of science and students' prior knowledge. Please summarize what you have learned from the class." Each preservice teacher types a reflection on the same document posted in the shared Cloud so that everyone can read each other's reflection. A preservice teacher's reflection on the class demonstrates meeting the learning goal of the class:

> I was surprised with how differently people think. I thought the purpose of this class was to show both the history of science and students' prior knowledge, based on the similarities between the two we need to examine the prior knowledge and find ways to improve them. However, many people in the class paid attention to the ways people change the ideas. I realized that people might see the same data but draw various conclusions. In the same vein, children's conclusions based on their own logic might be seen by others [adults] as misconceptions. I came to know that it takes a lot of time and effort to understand student ideas and improve them. I should be a teacher who probe student ideas prior to teaching and prepare for them. (Mr. JIH)

Professional vision. Once the preservice teachers are introduced to the development of scientific concepts in the history of science and in students, teaching for conceptual learning is discussed through the notion of conceptual change and teacher noticing (Driver & Oldham, 1986; Hashweh, 1986; Hewson & Hewson, 1984; Kang, 2007; Kang, 2014). In particular, three aspects are emphasized: (a) attending to what and how students think, (b) careful interpretation of student thinking, and (c) use of student ideas and thinking as resources for teaching. Based on the previous discussion on student prior knowledge, examples of using student ideas as resources for teaching are extensively discussed.

After the initial theoretical discussion, the preservice teachers are briefly introduced to instructional models (BSCS, 2006; Driver & Oldham, 1986; Hashweh, 1986). This provides a framework for planning a lesson. Then the preservice teachers are required to develop a lesson plan for student conceptual understanding. The main criterion for assessing the lesson plan is how properly student ideas are considered. The lesson plan must anticipate student thinking patterns, or ideas and ways to deal with them in the lesson.

Learning theories. After the detailed discussion on conceptual change learning and teaching, more learning theories are discussed. The discussion starts with an introduction to the process of conceptual equilibrium (accommodation, assimilation, equilibrium) proposed by Piaget (Fosnot, 2005). This discussion is used as a way to recapitulate use of student ideas in teaching for conceptual understanding. After the introduction, Bruner's discovery learning (Bruner, 1961; Schunk, 2012) and transmissional teaching and learning is described a means of comparison.

After the discussion on the cognitive process of conceptual change learning, a social constructivist perspective is introduced through the Vygotskian notion of the zone of proximal development (Vygotsky, 1978). This is compared with Pigetian developmental stages. Included in the discussion is conceptualization of the role of teachers. The role of teachers as facilitators of learning is discussed by introducing the needs for teachers' attending to and interpretations of student ideas and thinking, causing cognitive disequilibrium, scaffolding, and mediating student discourses.

At the end of the discussion on learning theories and the role of teachers, the preservice teachers are asked to generate outlines of imaginary lessons that are implemented from a conceptual change perspective, as well as a social constructivist perspective. To demonstrate their understanding of the two perspectives, the preservice teachers are asked to construct two lessons about one science topic taught from each of these two different perspectives. The lesson outlines should have a description of instructional processes, student reactions, and the role of teachers to show how the two lessons differ as they are based on different learning theories. The preservice teachers work on the task as a group and share with the whole cohort later. The task is mostly done in class so that the instructor can provide necessary coaching during the task. To enrich their repertoire of teaching, each group is asked to choose a science topic that is different from each other. Sharing these imagined lessons serves to sum up the entire discussion on learning theories. During this time, preservice teachers are asked to note the differences between the two perspectives that the preservice teachers applied to their lessons, as well as to compare both with Bruner's discovery learning.

Developing the Ability to Visualize Teaching Practices

After emphasizing the importance of student ideas in learning and teaching, the preservice teachers are invited to think about how to address student ideas in teaching. For this goal, science curricula goals are first discussed in order to get familiar with teaching content, along with a discussion on the nature of science and scientific inquiry. This is followed by an introduction to specific instructional models and strategies. Throughout these topics and activities, reflection (Kang, 2004; Schon, 1983) is emphasized using class discussion or reflective paper writing assignments in order to help the preservice teachers connect theory to practice. In so doing, a view of teaching as a profession is explicitly addressed.

Curricular emphasis. In the discussion of the content of learning, a brief history of changes to the national science curriculum is first addressed given that South Korea has adopted a national curriculum. The discussion focuses on changes in curricular emphasis (Roberts, 1982), which includes the emphasis on practical knowledge in the ‘50s, on disciplinary knowledge and inquiry in the ‘60s and ‘70s, on Science-Technology-Society (STS) in the ‘90s (Yager, 1993), and on scientific literacy since 2000 (Choi, Lee, Shin, Kim, & Krajcik, 2011). The importance of this topic lies in the role of teachers in selecting what to emphasize from the national curriculum and how to approach teaching the curriculum. Again using a jigsaw method, each group takes charge of comparing middle school science curricula of two different eras using the information on the web site that provides the entire national curriculum from the beginning of school science in the mid ‘50s. The comparison focuses on stated science curricula goals and purposes, and science content. Preservice teachers are supposed to find parts of content that display particular curricular emphases espoused during a certain era, and find those that are common across two eras. For example, curriculum with an STS emphasis may relate concepts to safety tool such as helmets and car seatbelts when discussing forces and motion, whereas disciplinary knowledge and inquiry emphasis may focus on Newton’s law through controlled experiments. After the comparison done by each group, a whole class discussion is held to share group results and to recapitulate the nature of each curricular emphasis. What is emphasized during the whole class discussion is the fact that these curricular emphases are not necessarily exclusive. Also emphasized is the role of a teacher who chooses and organizes learning content in alignment with a particular curricular emphasis.

After sharing the various curricular emphases, each group choose a physics topic and generates two middle school science units with different curricular emphases. For each unit, each group is asked to outline a content sequence and an explanation for the sequence in relationship to curricular emphasis of their choice. They utilize school textbooks as resources for the task.

Inquiry and the nature of science. Since the mid ‘70s, Korean national science curriculum has emphasized science inquiry as a skill for students to acquire. Understanding the nature of science has been a part of curricular purposes of science education since 2000. Due to the importance of these two topics in science education, these topics are addressed in-depth.

Inquiry in the national science curriculum has been defined as skills involved in doing scientific inquiry (National Curriculum Information Centre, n.d.; Padilla, 1990). Inquiry skills are divided into basic skills (observing, inferring, communicating, classifying, predicting, measuring) and integrated skills (controlling variables, defining operationally, formulating hypotheses, interpreting data, experimenting). Using their own lab experiences in schools and college, the preservice teachers are asked to discuss how each inquiry skill is used in school science.

After a brief introduction to these skills, four scientific reasoning skills (inductive reasoning, deductive reasoning, hypothetico-deductive reasoning, abductive reasoning) are discussed (Laudan, 1981). Examples of inquiry activities that use each of these reasoning skills are introduced, and then preservice teachers are asked to come up with such examples for middle and high school science or physics lessons. The examples are from school science activities. For example, a worksheet of reflection lab in which students are supposed to find reflection law from data collected is given as an example of inductive reasoning activity. Deductive reasoning is discussed through activities that ask predictions based on scientific laws (e.g., Newton's law). An explanation of sound from the rim of water-filled cup drawn from how string instruments make sound, which is already learned, is used as an example of abductive reasoning. Many confirmatory lab activities are introduced as examples of hypothetico-deductive reasoning. In discussing the topic, preservice teachers are strongly encouraged to carefully consider who is doing the reasoning during activities. This highlights the difference between student-led and teacher-led inquiry.

After discussing the basic elements of inquiry, a more global analysis of science inquiry is addressed by bringing in philosophical discussion on how scientific knowledge develops. T. S. Kuhn's scientific revolution (1996), K. Popper's refutations in science (Popper, 2002), and I. Lakatos' research programs in science (Lakatos, 1976) are introduced in terms of how each thinker explains scientific knowledge development differently. Historical examples given by these philosophers are used in discussing the topic, which provides preservice teachers with an opportunity to consider the historical background of the science concepts that they will teach.

Along with the discussion on different perspectives of scientific knowledge development, a student learning process as a way to develop their own knowledge is discussed. For example, preservice teachers are asked to discuss how students' conceptual change is analogous to scientific revolution, how the Lakatosian notion of creating an auxiliary hypothesis is analogous to students' idea development, and whether counterintuitive evidence can make students give up their prior ideas. These are in part recapitulations or rectification of previous discussion on the history of science and student prior knowledge. Although these discussions tend to simplify complex philosophical discussion on the subject, the link between scientific knowledge development and student knowledge development provides a rationale for the preservice teachers to know the nature of science inquiry. Also emphasized is a view that knowledge development in science is a learning process for scientists, much in the same way that students learn science. Connecting scientists to students empowers preservice teachers in physics learning and makes preservice teachers feel the need to empower their own students in learning science or physics (Kang, 2008).

After all of these series of activities, preservice teachers are again asked to write a reflection of what they have learned on a shared document. A preservice teacher's reflection on the class demonstrates the general outcome of the class:

> What I learned today is that scientific facts are the best valid opinion at the time constructed through data known until then. I've got to know that scientific facts are not unchangeable truth. I also realized that I should learn a lot in order to help my students in gaining logical thinking skills for doing inquiry. (Mr. LGW)

> In this class, I was reminded that just as scientists … pondered and argued for their opinions among various theories in search for exact answers, students also try to explain a phenomenon using causal reasoning of their own. For that reason and others, I should be a teacher who does not force students to believe that the theories in the textbook are the only right answers; rather I should provide opportunities for them to review their own logic and thinking in search for any flaws and contradictions so that they can expand their thinking skills. The class let me know that the purpose of a science class is not to tell students that "this is the right answer" in order to deliver knowledge pieces and fix students' ways of thinking. Rather science class should be the time when students think scientifically and logically. (Ms. LJA)

The links that the preservice teachers make between science inquiry and student learning and their role as a teacher indicates that they are in the pathway to becoming the sort of teacher intended by the course. When sharing these reflections in class, the preservice teachers are asked to infer the kind of teacher intended in the course and to share their images of productive science teachers. Included in the discussion is an image of teachers who care for student ideas and empower students in science learning by providing opportunities to use their thinking and to have authentic inquiry experiences.

Instructional models and strategies. Up to this point, preservice teachers have learned about student learning processes and frameworks to organize learning contents. When discussing each topic, teacher's role has been briefly mentioned and emphasized. Based on these general discussions of teacher role, instructional models and strategies are addressed. Learning cycle, analogies, Prediction-Observation-Explanation (POE) method (White & Gunstone, 1992), concept map (Novak, 1990), V-diagram (Novak & Gowin, 1984), and role-play are introduced.

In the discussion of the strategies, it is emphasized that each strategy is not necessarily related to a certain learning theory, whereas certain strategies are better than others when teaching certain topics. After a brief introduction to various teaching strategies, the preservice teachers are asked to come up with a science lesson employing certain strategies as a group. The task is for them to understand how to select strategies based on the learning contents and ways to implement each strategy. Because real lessons typically use multiple teaching strategies, I ask them to use at least two strategies at the same time so that they can think of connections between strategies and lesson content.

Developing Teaching Competencies: Teaching Demonstration

Once equipped with learning theories, curricular emphases, and teaching strategies, the preservice teachers are ready to practice teaching individually. Each preservice teacher experiences one cycle of planning-teaching-reflection. The cycle is introduced as a fundamental element of a regular teaching routine where one cycle leads to another.

Each preservice teacher is asked to plan five, 15-minute short lessons that use each of the five teaching strategies discussed previously. They post all five on the Cloud to share with each other. Each preservice teacher is given a chance to practice teaching one of the five short lessons in class. The preservice teachers can choose any topic from middle school science or high school physics curriculum. Each short lesson plan should include (1) learning objectives achievable through a 15-minute lesson, (2) a description of how a teaching strategy is used by the teacher and students, and (3) ways to know whether the learning objectives achieved by students.

To guide the practice, five evaluation criteria are presented beforehand: (1) Is the lesson run smoothly? (2) Is the strategy properly utilized? (3) Is the lesson responsive to the reactions of pseudo students (peers)? (4) Is there evidence that the lesson objectives are achieved? (5) Does the lesson have new or creative elements? The creative element is required in order to prevent the preservice teachers from copying examples discussed in class.

After each short lesson demonstration, each audience member provides individual written feedback on the lesson using the evaluation criteria. This feedback is given to the lesson demonstrator, and the instructor provides verbal feedback on the lesson right after demonstration for all class to listen together. This demonstration and feedback loop is extensive, and takes about 30 minutes per short lesson demonstration.

Each teaching demonstration is video recorded, and the preservice teachers are asked to review their own video recorded lesson and write a reflection paper. The reflection is a self-evaluation of the lesson using the lesson evaluation criteria. Their peers' written feedback and the instructor's verbal feedback are expected to be utilized for their reflection.

Although the process is time intensive, the preservice teachers in the course appreciate the opportunity to practice. In particular, watching their peers' lesson demonstration is valued as much as their own lesson practice as it allows for them to recognize different ideas about teaching. The requirement of using certain strategies seems to make the preservice teachers think and study more about how to teach a topic. However, the demonstration is limited in that it fails to provide the preservice teachers with an opportunity to learn from interactions with real students.

Science laboratory work, fieldwork and safety. Due to the practical importance of the topic, science laboratory, fieldwork and safety are addressed in separate with a focus on how to and what to do. Because the topic is addressed near the end of the semester, each year the time given to the topic varies depending on how much additional time is spent on the preceding topics. At least, preservice teachers are asked to review laboratory activities in school textbooks and to develop one lab activity worksheet based on their own view of student learning from laboratory activities. Also required is a plan for lab safety instruction. In this case, some preservice teachers develop lab safety rules to post on the wall. Others develop a contract that they ask students to read and sign on the first day of class.

When time allows, preservice teachers are asked to plan a field trip or fieldwork for science activities. In this project, they are supposed to investigate school regulations or rules for safety and school conditions such as budget and school schedule. Also, an Microcomputer-Based Laboratory (MBL) activity is practiced in a way that groups of four conduct laboratory activities about topics different from each other using MBL and report advantages and disadvantages of using MBL in science teaching and learning. Typical sensors or probes used include sensors for temperature, motion, pH, gas pressure, CO2, electric current, and relative humidity.

MLB is not widely used in South Korea, and thus the topic is addressed with a purpose to expose to a different way that science laboratory activities are conducted. More importantly, MBL activity is used to discuss how contemporary science utilizes advanced technologies in collecting and analysing data, how science and technology advance each other, and how to exhibit this nature in school science. Use of computer and computer simulations are naturally discussed.

CLASSROOM PRACTICE: VIGNETTE OF A SIGNATURE LESSON

A typical class on a topic is as follows: The class begins with a brief check in of previously assigned reading, using the questions posted on the shared Cloud, and then the day's activities are introduced. Group and whole class discussions on the topic of the day proceed. Each group starts working on a group task. After finishing the group task, each group presents their work and evaluate each other. For selected lessons, preservice teachers are asked to reflect on the class on a shared document.

Here is a vignette of a class on learning theories. As usual, the preservice teachers are asked to read course materials on Bruner's discovery learning (Bruner, 1961), Piagetian conceptual change learning (Fosnot, 2005), and Vygotskian social constructivist learning (Vygotsky, 1978) before class, and post topics or questions for discussion on a shared document one day prior to class. They are encouraged to make their questions or topic for discussion related to classroom practices so that they can link theory to practice. When preservice teachers post their ideas, they are required to read what others have posted prior to them so that each posted idea is different from each other, and latter postings may answer the previous postings and add new ideas.

I read the postings before class and sort out the topics to fit them in one three-hour class, and to identify points that require further elaboration. When the class starts, most members in class are aware of the questions or topics for discussion. An example of posted questions or ideas for discussion is the following:

> Bruner claims that core ideas can be translated into three modes—enactive representation, iconic representation, symbolic representation—in alignment

> with students' developmental stages. Can we represent theory of relativity in enactive and iconic representations? If not, there is a core idea that cannot be translated for young students. How can we teach the idea then? (Mr. YDJ)
>
> What is the difference between Piagetian and Vygoskian learning progress? (Mr. JYK)
>
> One of the causes for misconceptions is conversation with the outside world. For example, in a warrior's game, an enemy falls down forward, not backward (conservation of momentum is not followed). Let's discuss what some of the scientifically flawed ideas shown in movies, online, and in games. (Mr. KHC)

When the class convenes, I ask the preservice teachers as a group to discuss the questions or topics for discussion that they themselves posted. In so doing, all the topics and questions posted can be addressed. During group discussion, each group member elaborates his/her posting. During this time, I ask them to refer to course reading materials for clarifications of their understandings. I walk around the groups listening to each group's discussion and sometimes join the discussion for clarification of theories or preservice teachers' ideas that are on the table. The preservice teachers can call me to ask questions that they cannot resolve themselves.

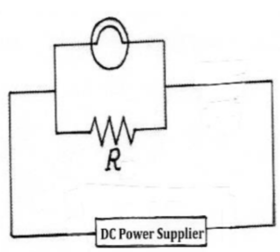
After about 15–20 minutes of group discussion, I convene a whole class discussion. In this whole class discussion, the preservice teachers share not only their individual ideas but also what they have come up with during group discussion. In general, the preservice teachers find similar ideas challenging. For example, few grasp the differences between Piagetian and Vygotskian view of learning progress. By asking questions, I ensure the whole class discussion include that Piagetian emphasis on individual cognitive processes through interactions with phenomena or ideas is distinguished from Vygotskian emphasis on social tools (e.g., language, computer) and support provided by knowledgeable others. In order to check their understanding, I ask the preservice teachers to come up with an example of student learning processes that can be explained by Piagetian or Vygotskian theory of learning. In summary, I point out that what is happening in the mind of individual child is of interest to Piagetian theory while how a student can learn with the help of tools or adult support is what Vygotskian theory tries to explain. In so doing, I ensure that the preservice teachers view that various learning theories are complementary rather than conflicting.

Typically, there is not enough time to discuss all aspects of learning theories, and thus I try to ensure that the preservice teachers have grasped about how each learning theory can be practiced in classroom teaching and learning. This comparison, however, always risks simplifying each theory.

ASSESSMENT: VIGNETTE OF A SIGNATURE ASSESSMENT

Many of the group and individual tasks completed during the class are formatively assessed and make up 70% of course grading including 10% of participation and attendance. An example of formative assessment is a class task completed as a group: Designing a science laboratory activity sheet for middle school students in which students use at least two types of scientific reasoning out of inductive, deductive, hypothetico-deductive and abductive reasoning. They also have to explain in writing when and how students are supposed to use the purported reasoning. Middle school science textbooks are given to each group for reference. To guide the activity, assessment criteria are also given, which include (a) whether reasoning is properly designed and (b) whether the guiding questions are properly asked to the level of intended students. While each group designs the activity I walk around the groups probing their ideas and providing feedback. Upon completion, each group presents their work to the whole class and receives feedback from their peers as well as the instructor. This activity and other class tasks provide information on the degree to which the preservice teachers are able to create a science lesson and visualize how to teach.

There is also an essay test that makes up 30% of the course grade. This essay test is a summative assessment that is administered at the end of the semester. The essay test questions ask about most topics of the course that can be discussed in writing. Test questions reflect the class activities, so those who have participated in class activities and discussions should be able to anticipate what they will be tested on. However, the specific context of questions is new, and thus the ability to apply what has been discussed and practiced in class to new teaching situations or content is evaluated. From time to time, when certain important topics are not fully discussed in class due to time limitations, I explicitly mention that it will be asked in the essay test so that the preservice teachers spend more time on the topic outside of class.



A middle school student answered the following on a formative assessment.

Question. The bulb in the circuit is lighting. What will happen when the resistance in the circuit increases?
Student response: "The bulb will become brighter because the current flowing through the bulb will increase as much as the electric current flowing through the resistor decreases."

(1) Describe a possible teaching move based on Piagetian learning theory.
(2) Describe a possible teaching move based on Vygotskian learning theory.
(3) Compare your answers to (1) and (2) to clarify the difference between the two learning theories.

Figure 1. Summative test question example

Figure 1 is one example of a question in the summative test. In this scenario, the student response represents a common alternative idea in electricity. The preservice teachers are asked to come up with lesson plans based on learning theories.

Some of the preservice teachers' responses were analysed and compared with those of inservice teachers in my study (Kang, 2015). Once the essay test is administered, grading rubrics (Table 3) are provided to the preservice teachers in order to help them learn from the test. The evaluation criteria for the example question are the following:

Table 3. An example of grading rubrics item

Item	*Score*
(1) Does the answer addresses cognitive equilibrium process with a proper example of cognitive conflict suggested?	4
(2) Does the answer provide an interpretation of ZPD of the student in the scenario and suggest proper scaffolding?	4
(3) Does the comparison focus on the different foci of the two theories (individual vs. social cognitive process) and different roles of teachers?	2

The essay question is also reflective of the National Teacher Employment Examination in that the questions are similarly constructed. However, the essay questions used in the course are less specific and more comprehensive than those of the national exam.[8]

CONCLUSION: STRENGTHS AND AREAS FOR IMPROVEMENT

The methods course described in this chapter is for physics preservice teachers who will be teaching middle school science, high school general science, or physics. The course has its strengths and weaknesses.

One of the strengths of the course is the connection between theory and practice. Although preservice teachers in the course do not have opportunities to practice their teaching in a real classroom, the course is designed so that every theoretical discussion is followed by discussion of practical applications to teaching. Preservice teachers are given opportunities to imagine how they will use the theory with real students, making the course content relevant and usable. The short lesson demonstration is the culminating experience for the preservice teachers to link theory to practice.

The connection between theory and practice is also the primary weakness of the course. Obviously, thinking with an imagined classroom or pseudo students falls short of an authentic experience. The perception that what is discussed and practiced is not real may encourage preservice teachers to dismiss what they have learned when an application fails in a real teaching situation, unless they have strong beliefs in what they have learned.

The content of the methods course may include more than it should and thus be less focused. The main constraints include that (a) it should prepare preservice teachers for practicum and (b) the course is responsible for the National Teacher Employment Examination. For these reasons, there is a push to address all the key elements of teaching science in the classroom and the content to be tested. This is a lot of material for one course to address, and thus following courses, i.e., PRW and PTM revisit some of the topics such as scientific reasoning, instructional models and teaching strategies.

NOTES

1 In the year 2013, there were about 3.7 million secondary school students in South Korea.

2 Korea adopts a national curriculum in which general science is offered from grades 3 till 10 as required courses and then discipline-specific subjects such as physics, biology, and others are offered as elective courses for grades 10 to 12.

3 One credit means one hour per week for at least 15 weeks. Typically colleges of education requires 140~150 credits for BS degree.

4 Those who take the second round test are selected from the first round test. While the first round test is administered nationally, each local educational agency administers the second round test for those who have applied for their school districts. While details of the test vary across districts, a general format consists of a 15 minute demonstration of teaching (the same lesson topic is given to all applicants of the same teaching subject) and a 10 minute individual interview. The examiners include school administrators and senior teachers.

5 Currently, all undergraduate level teacher education programs in Korea offer four-year (8 semesters) programs.

6 In Korea, the academic year starts in March and ends in February. Every fall semester (from late August till February), the college entrance application is collected twice nationwide, while the national college entrance exam is offered once during this time. Each program in college selects their students from the pool of applicants twice, once based on student high school records and their interview (with minimum college entrance exam scores required), and the second time based solely on college entrance exam scores. Based on the popularity of particular education programs, students of different achievement levels apply for different programs. Thus, each teacher education program has different selection criteria for GPA, college entrance exam scores and so on. Science education programs are, in general, fairly popular, and the top 10% of high school students overall usually enter science teacher education programs.

7 Licensure requirement includes a minimum of four weeks of full time practicum, but the teacher education program reported in this chapter requires more than the minimum. To the best of the author's knowledge, eight weeks of full time practicum is currently the maximum accomplished for the requirement by those in physics teacher education programs in Korea. During the full time practicum, preservice teachers stay in school to the same extent that full time teachers do. Courses offered to juniors in the fifth semester, and seniors in the sixth semester, are scheduled such that full time practicum is possible without attending classes on campus.

8 It is not intended to design the course or course assessment to prepare the preservice teachers for the employment exam. However, the emphasis on applying theories to classroom situations is what is emphasized both in the course and the exam. As of yet, there is no research that links course grades to exam scores because exam scores are not disclosed.

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12. TEACHING METHODS FOR EARTH SCIENCE

INTRODUCTION

The Earth and environmental challenges facing our global society in the twenty-first century require robust understandings of the complexities of the ever-changing Earth system. Therefore it is critically important for Earth Science to be a central part of the secondary school science curriculum for all students, regardless of location or status. In some ways Earth Science may be considered the easiest of the science disciplines for students to learn about. After all, the Earth is all around us and we interact with it every day. Children are naturally curious about what the world is like and why things in the environment happen. Learning how to care for and preserve the environment for current and future living organisms, from pandas to polar bears to future generations of humans, is a natural source of motivation for students to learn about the Earth.

On the other hand, however, Earth Science is among the most challenging science subjects to teach, for two reasons. First, the Earth itself is 18 orders of magnitude larger than most classrooms. Earth processes operate at time and spatial scales that are much too large and slow to fit into a classroom for students to experience directly (Kastens & Rivet, 2010). In fact, research has shown that very large spatial and temporal scales are exceptionally difficult for people of all ages to grasp (Dodick & Orion, 2003; Kastens & Ishkikawa, 2006; Plummer, 2014). This leads to the second key challenge related to Earth Science education: although the Earth seems static and stable, it is in fact constantly changing in complex yet predictable ways. The dynamic interactions between the geosphere, hydrosphere, atmosphere and biosphere create complex phenomena that operate on a range of scales from seconds to millennia. But the consistency and complexity of these interactions between systems are difficult to observe, and are often overlooked or misunderstood in typical descriptions of the Earth's features and behaviours (Assaraf & Orion, 2005; Raia, 2008).

These factors mean that Earth Science teachers need to be well prepared not just in the centrally related disciplines of geology, hydrology, oceanography, atmospheric science and astronomy, but also possess a set of skills and knowledge that address the conceptual challenges of developing understandings of the full-scale Earth system while simultaneously leveraging the inherent interest and motivation of students in understanding the world around them. My course in the Science Education teacher

A. J. Sickel & S. B. Witzig (Eds.), Designing and Teaching the Secondary Science Methods Course, 207–221.

preparation program at Teachers College Columbia University is my best attempt to achieve these ambitious goals.

UNIVERSITY CONTEXT

My institution, Teachers College at Columbia University, is located in New York City, which is the largest city in New York State and the second largest city in the United States. Among other degrees, the Science Education program at Teachers College awards masters degrees in science teaching with teacher certification for grades 7–12 in New York State. New York State is one of the few states that certify secondary science teachers by discipline in one of four content areas: Biology, Chemistry, Physics and Earth Science. Our program provides specific courses and experiences to meet the instructional needs for pre-service teachers to become qualified in each of these areas, including content and teaching methods courses in Earth Science. These are the courses that I teach as part of this program.

New York State is also unique in that it has a long history of state assessments, particularly at the secondary level. These assessments are referred to as New York State Regents exams, and have been in existence since the 1960's. Regents exams are offered in subjects across the curriculum, including Earth Science, Biology, Chemistry and Physics exams for science (Liu & Fulmer, 2008). Students are required to pass a set of Regents exams, including two science exams in the areas of their choice, in order to receive a Regents-endorsed high school diploma. In our program, we emphasize preparation for teachers to address the state curriculum associated with the science Regents exams, although not exclusively so.

Teachers College is exclusively a graduate institution and awards only masters and doctoral degrees. Pre-service teachers are admitted to the program with a bachelors degree in the science discipline they are intending to be certified to teach, or at minimum with sufficient undergraduate course credits in that area. Our masters degree in Science Education with teacher certification program is a 14-month program. Pre-service teachers complete courses in a variety of areas including science content, teaching methods, literacy, differentiation and special education. They complete 100 hours of secondary classroom observations their first semester and two 6-week student teaching placements in the second semester, one in middle school (grades 7–8) and one in high school (grades 9–12). These classroom observations and teaching experiences are supported through university seminars on teaching and learning, which are completed concurrently with pre-service teachers' other coursework including methods courses but are distinct from those courses. In terms of methods courses, pre-service teachers take one general science methods course and one subject-specific methods course. The Earth Science methods course described here meets the subject-specific teaching methods requirement for those pre-service teachers intending to become certified as secondary Earth Science teachers in New York State.

The field of science education in the United States is currently in a transition, marked by challenging innovations in instruction, curriculum and assessment called for in the *Framework for K-12 Science Education* (National Research Council, 2012) and the *Next Generation Science Standards* (NGSS Lead States, 2013). This course, along with other courses across the science education program at Teachers College, strives to prepare the next generation of science teachers by equipping them with the knowledge, resources, and pedagogical expertise to address the new goals for science teaching and learning. In particular, recent iterations of the course have explicitly framed learning from the perspective of integrating disciplinary core ideas, crosscutting concepts, and science and engineering practices to develop robust three-dimensional science understanding of Earth science (Krajcik, Codere, Dahsah, Bayer, & Mun, 2014). This approach is reflected in both the class activities and overall structure of the course design, which is focused on developing pre-service teachers' pedagogical content knowledge for Earth Science teaching.

PLANNING: DISCUSSION OF COURSE DESIGN

As mentioned in the introduction, Earth Science is uniquely distinct from the other sciences in several different ways. These distinctions shape the goals and outcomes I have for the course, entitled "Teaching and Learning Concepts in Earth Science".

Philosophical Focus: Pedagogical Content Knowledge

The major outcomes of the course are driven by the goal of constructing a learning experience for pre-service teachers where they can develop their own pedagogical content knowledge for Earth Science teaching. Pedagogical content knowledge (PCK) refers to what teachers need to know about the content to help learners come to understand it (Gess-Newsome & Lederman, 2001; Magnusson, Krajick, & Borko, 1999). That means not only understanding the key ideas of the discipline, but also being aware of common student misconceptions, ability to make use of a wide array of different representations and explanations for concepts, knowledge of how to engage students in different forms of investigation, inquiry, and reasoning in the domain, and a suite of assessment tools and strategies to inform their instruction on an ongoing basis. The literature on science teachers' PCK informed both the pedagogical topics addressed in the course, as well as the focus and sequence of the short assignments and final project used to assess student growth and learning over the semester.

As teacher candidates come into the program with content knowledge in the discipline in the form of a bachelors degree or equivalent, I do not address the content included in a typical secondary Earth Science course in a systematic or comprehensive way. However, I do address key ideas and core concepts in the context of developing tools and strategies for pre-service teachers to build their PCK of those ideas through their own practice.

The following is the specific course objectives for this course as stated in the syllabus:

> This course is focused on developing your pedagogical content knowledge (PCK) in Earth Science. This includes exploring students' prior ideas about Earth processes; identifying key analogies, metaphors, and models to facilitate student thinking about specific ideas, developing demonstrations, activities and investigations about various Earth Science topics, and examining a variety of resources to use in your teaching of Earth Science. Each of these aspects of PCK will be examined in the context of important content and process ideas in the Earth Science fields. The major course goal is to provide you with appropriate experiences for initial growth as a professional educator who will teach Earth Science to middle and secondary students, and the knowledge and tools to develop your expertise further.

Course Sequence

The course is structured to address both pedagogical and Earth Science content objectives concurrently in the same lessons. The sequence of the lessons is planned first from a pedagogical perspective, considering how to best support pre-service teachers in building their pedagogical content knowledge. The order of these PCK topics generally follows a backwards design approach (Wiggins & McTighe, 2005). The beginning of the course starts first with how to articulate learning goals for three-dimensional understanding of Earth Science (Krajcik et al., 2014; National Research Council, 2012), then moves to ways to identify students' prior ideas of Earth science phenomena that inform instruction, which is then followed by developing expertise with a range of representations used in Earth science (including maps, graphs and models), and instructional strategies and approaches such as investigations and field work to achieve targeted Earth Science learning goals in the classroom. The Earth Science content topic for each week is selected to best support and illustrate the pedagogical focus of the lesson while ensuring that the overall breadth of key ideas in Earth Science are adequately addressed, in particular those that are included in the New York State Regents Earth Science curriculum for high school. While specifically attending to those content topics is important, they do not serve as the driving force for the planning of the course.

Course Structure and Assessments

During the semester pre-service teachers are assigned two types of readings in preparation for each week's lesson, one focused on the pedagogical topic and one on the Earth Science topic (Table 1). For example, in Week 2 pre-service teachers read a chapter from the text *Learning by Design* (Wiggins & McTighe, 2005) and an article that summarizes research on middle school students' understandings of basic

Table 1. Sequence of topics for Earth Science Methods course

Course session	*Pedagogical topic*	*Earth Science content topic*	*Assessment*
Week 1	Introduction, PCK	Nature of Earth Science	
Week 2	Learning goals	Solar system & celestial objects	
Week 3	Students' prior ideas	Causes of the seasons	Part 1 due
Week 4	Visualizations & diagrams	Convection & cycling; energy transfer	
Week 5	Models	Moon phases & eclipses	
Week 6	Maps & spatial reasoning	Plate tectonics; structure of Earth's interior	Part 2 due
Week 7	Data representations part 1: Graphs	Ocean circulation and tides	
Week 8	Data representations part 2: GIS	Topography & bathymetry	
Week 9	Investigations in Earth Science: Intro	Weathering	Part 3 due
Week 10	Investigations with models	Erosion & deposition; landforms	
Week 11	Investigations with data	Weather & climate patterns	
Week 12	Realia: Bringing Earth into the classroom	Rock types and rock cycle	Part 4 due
Week 13: FIELD TRIP TO CENTRAL PARK	Learning in the field	Geologic time; glacial geology	
Week 14	Human/environment interactions	Global climate change	
Week 15	Final presentations		Final project due

astronomy concepts (Trumper, 2001). Pre-service teachers are expected to come to class ready to discuss these readings in relation to the classroom activities and apply the science concepts to their work. Weekly attendance, participation and informed contributions to the class activities and discussion are significant parts of the course assessment, together constituting 20% of the final course grade.

In addition, there are four short assignments that pre-service teachers complete over the course of the semester. These assignments are each evaluated as 10% of the final course grade, and each constitutes a key part of the final class project, which is to build a PCK resource guide for a particular Earth Science concept that can be shared with other members of the class. At the beginning of the semester each pre-service teacher selects a key concept in Earth Science that they want to focus on in these short assignments. The short assignments in turn ask pre-service teachers to consider the topic from different pedagogical perspectives. The Part 1 assignment asks them to describe the topic in terms of learning goals and state why it is important for teachers to teach and students to learn (which are not typically the same reason). The Part 2 assignment asks pre-service teachers to identify common conceptions and prior ideas that students may have about the topic, either through a literature review or by interviewing young people directly. The Part 3 assignment asks them to identify three different types of representations on the topic (a diagram, a model, and a data display) and critique each one for its affordances and limitations using a set of criteria developed in class (this process is illustrated in more detail in the next section). The Part 4 assignment asks pre-service teachers to develop or adapt an inquiry experience for students on the topic and describe the inquiry from both the students' and teacher's perspective.

The final project of the course, which contributes to 40% of the final course grade, brings together the short assignments into a comprehensive teaching resource on a particular Earth Science topic that the pre-service teachers can share with other members of the class. This project is described in more detail later in the chapter.

CLASSROOM PRACTICE: VIGNETTE OF A SIGNATURE LESSON

Here I present in depth the lesson where pre-service teachers learn about and critique representational diagrams of Earth system structures and processes, which then serves as the basis for the Part 3 portion of their final assignment. As the majority of Earth Science phenomena under study are too big or too slow to investigate directly in a classroom, representations of these phenomena abound in Earth science instruction and are essential tools that Earth scientists use to investigate and communicate explanations for how the Earth system operates (Kastens & Rivet, 2008). Thus understanding the roles, explanatory power, and limitations of a range of different kinds representations is central to learning and teaching in this field. This lesson is aimed towards developing pre-service teachers' PCK around representational diagrams and provides strategies for helping their students learn to use and critique diagrams effectively. Over the years I have selected a variety of different Earth Science topics to serve as the context for this lesson, including the structure of the atmosphere, energy movement (conduction, convection, and radiation) in the Earth system, and geologic time. In this vignette, the focus of this lesson is on understanding representations of the structure of the interior of the Earth.

I start the lesson by introducing the focus Earth Science topic for the day, in this case the structure of the interior of the Earth. I state that I first want to know what the pre-service teachers understand and how they visualize this important aspect of the Earth that cannot be seen directly. I direct the pre-service teachers to each create their own diagrams of the Earth's interior structure.

After each pre-service teacher has individually created their own representation of the interior structure of the Earth, I ask them to compare their drawings in pairs or small groups. They are to discuss what is the same between the drawings, what is different, and why that might be. I ask them to pay attention to *what* was represented in the drawings and *how* it was represented, in terms of their commonalities and differences. The pairs or small groups talk for about five minutes, and then they share their comparisons in a whole class discussion. The features they tend to have in common include a circle or sphere that represents the Earth as a whole, some indication of interior layers, a thin or small surface layer, and some type of circular or central core. Differences often include the size or patterns used to mark the different layers, the use of labels or arrows, and the inclusion of any features on the surface of the Earth (such as mountains, oceans, or volcanoes).

After this brief class sharing, I then present some background on the use of representations and models in Earth Science. In a short PowerPoint presentation, I focus on the use of representations from a PCK perspective, and in particular on what teachers need to know about representations in order for them to be used as effective tools for teaching and learning. I explain to the class the following important considerations regarding the use of pictures and diagrams specifically in Earth Science teaching:

> When you think about teaching Earth Science, or any science, or any idea or concept, there are many modes used to transmit that knowledge, including representations of the concept or idea.
>
> In our class, we are considering what teachers need to know about those representations in order for them to be effective tools for teaching and learning. Today the focus is on teaching about the structure of the interior of the Earth and pictoral representations used to do this. Remember the things about PCK that we're been talking about in this class. We are trying to consider and develop that tacit knowledge that master teachers have developed about ways of teaching specific content ideas effectively and helping students understand these ideas and connect them to other understandings.

I have prepared a set of eight to ten representations of the interior structure of the Earth that I have gathered from websites and textbooks. I display the first one on the Smart Board or use a projector (Figure 1). I ask the class to brainstorm together some guidelines that they should consider when using the image with students, explaining to the class the following:

> Now when we as teachers are thinking about using certain pictures, diagrams, models, visualizations, animations, or analogies in the classroom we need to think about what they offer in terms of helping students grasp ideas, and what we need to be aware of so that they are used properly. What are some of the aspects of the picture that you need to consider?

Figure 1. First Earth structure image[1]
The image is presented to pre-service teachers in color, as follows: Ocean/blue, land/green, crust/brown, mantle/orange, outer core/tan, inner core/yellow

Together, we examine the first image on the screen and make a list on the board of observations and questions that teachers should ask themselves (and potentially their students) about this specific diagram. The class discussion starts with what the image is intended to show and possible (mis)interpretations of different features of the diagram including colors, shape, lines or arrows, and location or size of prominent features. For example, for the image in Figure 1, pre-service teachers note that it definitely represented the Earth because of the iconic globe features on the outside of the sphere. However, there is some possible confusion about the colored triangle-shaped features in the upper middle of the globe. Is it possible to look at the image and think that the layers inside the Earth only exist in that section of the Earth? Also, the pre-service teachers note that layers are not spheres, but triangle-like in shape. So does that indicate that the interior of the Earth is possibly a set of nested triangle layers? Then there is also the issue of colors. Are the yellow, orange, and red colors of the triangles meant to indicate there are just distinct layers, or do the colors convey some relative characteristic of the layers, such as temperature or density? Or, are the layers inside the Earth *actually* colored yellow, orange and red, in the way that the oceans on the exterior globe are blue similar to how they are in real life? In addition, there is also the issue of scale: the inner core looks to be about the size of Africa in the picture. Is this actually the size of the core? Through discussion we generally agree that this is not the case, but we note that there is no scale or key in this figure to help the learner interpret the shapes, sizes, or colors of the image features. This discussion raises an important point: images, figures and diagrams are produced and shared with a set of underlying assumptions about the ways that the image represents the concept, process or structure it is trying to convey. But oftentimes we don't recognize or acknowledge these assumptions. Rather, we use our own prior knowledge and experiences to draw conclusions about what the representation is trying to convey. However, when we use these figures and images with our students, they may *or may not* bring the same prior knowledge and experiences to their interpretations. Thus it is important to be clear with students about what they understand, what their alternate interpretations could be, and how to support them in developing the skills and knowledge to effective use these and other similar diagrams.

As pre-service teachers are discussing the image, I create a running list of questions, topics and features on the board: What is the diagram trying to show? What do the colors indicate? What do the shapes mean? What does the relative size/scale of objects show? What do the arrows/lines mean? What features are showing context or points of reference? Is there a title? Is there a key? These questions written on the board then begin to frame the list of criteria by which teachers should critique each of the images or representations they use as part of their instruction, with respect to their goals for student learning.

This process is repeated with the second image of the interior of the Earth that I show on the Smart Board or projector (Figure 2). Once displayed, I ask the class to examine this image using our current list of critique criteria, and to consider two additional questions: (a) what is this figure trying to convey? and (b) how is it similar and different from the first figure?

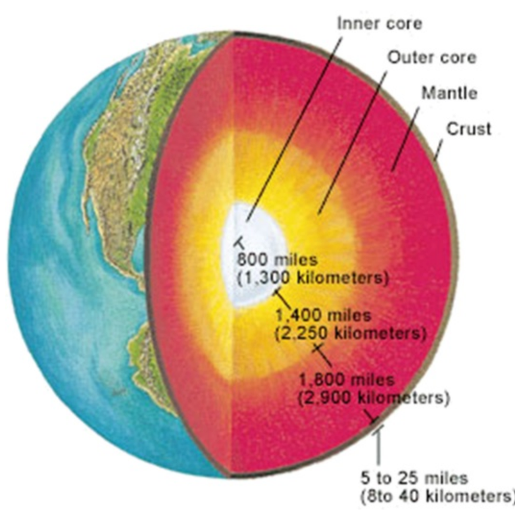

Figure 2. Second image of the interior of the Earth[2]
The image is presented to pre-service teachers in color, as follows: Ocean/blue, land/green, crust/grey, mantle/red, outer core/yellow, inner core/white

This comparison between the two images leads to an interesting discussion about representations. The pre-service teachers see how the globe is similarly represented, but the interior of the Earth is quite different. In this figure, they can see the layers as concentric spheres rather than nested triangles. They note that the labels are present, and this image includes a scale that indicates depth. A key observation is that the colors used for the layers have some differences when compared to the previous image. This leads to another important class discussion about the *affordances* of each image. What is this image good at helping learners understand, that the first image was not? Through discussion, the class comes to understand the point that not all representations of a specific Earth process or phenomena are equal; different images foreground different aspects of the complexity of the real world. It is important for them as future teachers to pay attention to the alignment between their learning goals for their students and what the representation conveys most effectively. If the representation and the learning goals for a particular topic are not in alignment, the representation may simply lead to confusion for their future students, and it is time to look for a different representation.

I repeat this critique and discussion process further with three or four additional images of the interior structure of the Earth (Figure 3). For each image, we together as a class compare it to the previous diagrams in terms of its affordances, strengths and weaknesses. After each discussion we add to or amend our class list of critique criteria questions that I have written on the board.

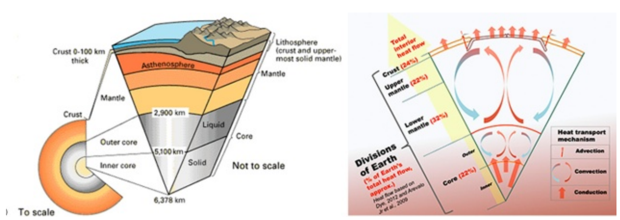

Figure 3. Additional diagrams of Earth's interior[3]

Then the class breaks into groups of three or four pre-service teachers. I give each group the same selection of three additional pictures, and together they discuss and apply the class criteria to critiquing the affordances and limitations of each image. Each person in the group is responsible for taking notes on one of the images. Then I jigsaw the class, grouping together all the pre-service teachers who took notes on image 1, image 2, and image 3 together. In these new groups, the pre-service teachers share and compare their critiques of that image. The focus questions for this sharing time include, was the use of the class criteria consistent? And, where are the areas of confusion, or places where the criteria need more clarification or specificity?

Each group shares the findings from the jigsaw discussions, and together we refine and finalize the criteria to use when considering what diagrams, figures, images and models to use as part of their instruction. The pre-service teachers then apply these class critique criteria to representations on a topic of their choice as part of their final project for the course.

As the class ends, I show the remaining several image slides of the topic for the day. I emphasize that there are *lots* of different ways to represent not only this idea, but all of the core ideas in Earth Science. I return to the point that it is a key part of Earth Science teachers' PCK for them to be aware of the range of different representations, and how to identify the affordances and limitations of these representations in ways that best meet the learning goals for their instruction and the needs of their students.

The walk-away points for this lesson are for pre-service teachers to be aware that all different representations have both affordances and limitations. There is no one representation that is going to perfectly show the science concept, and every representation is subject to multiple different interpretations. Thus it is critically important that as future teachers, they do not assume their students understand the science just by looking at a diagram. A range of different representations are often needed to help students understand the full breath of these complex Earth Science concepts and processes.

ASSESSMENT: SUMMATIVE PCK PROJECT

The key assessment for the class is for each pre-service teacher to develop a PCK resource guide for teaching a topic in Earth Science. The PCK resource guide that they create is a coherent 15 to 20-page compendium of instructional resources on a single topic in the Earth Science curriculum. It includes several parts, each of which has been built over the semester as part of the four short assignments: (a) a description of an Earth Science topic of their choosing; (b) alignment of that topic with state and national standards; (c) a summary of common misconceptions or prior ideas that students commonly have around the topic (from their own investigation or the literature); (d) three different kinds of representations and a critique of each using the set of review criteria we developed as a class; (e) a description of an inquiry investigation that integrates scientific practices and crosscutting concepts with their chosen topic and highlights key pedagogical strategies related to that topic, and (f) a list of three key resources that could be used by teachers and students to teach or learn more about their topic. These completed PCK guides are presented and shared with members of the class at the end of the semester. This means that as the pre-service teachers leave the class and move on to their first teaching positions, they each have a set of resources on a range of topics developed by their peers that they can use to start planning their own classroom lessons and units.

Although a bit unusual, there are several reasons for why I chose to have the final project for the course build from the series of short assignments over the semester. First, it gives pre-service teachers an opportunity to see how the different aspects of their developing Earth Science PCK are related and connected in the context of a single topic. Developing the project over time allows for reflection and revision of the different components (Reiser, 2004). It allows them to experience the process of developing expertise in teaching one area of the Earth Science curriculum in depth, as a model for how they should go about learning and planning other areas of the curriculum. It also provides an opportunity to share that expertise with their classmates, fostering a community of learners in the course (Brown, 1997).

Evaluation of this summative project is conducted across several dimensions. The first dimension of evaluation is if the project is completed on time with all of the required components. The second dimension of the evaluation focuses on the understanding of the Earth Science topic chosen, and in particular, how the descriptions, representations and inquiry experiences described in the PCK guide reflect an understanding of the Earth Science concept, process, or idea in a way that is both accurate (absent of errors or inconsistencies) and is beyond what the target student population is expected to understand. Related to this point, it is important that the focus topic does not shift or expand in scope throughout the PCK guide.

A third dimension of evaluation of the PCK resource guide attends to the ways in which the guide reflects an understanding of how learners (the future students of the pre-service teachers) think about their chosen Earth Science topic. This aspect of the PCK resource guide is one that I have found to be particularly challenging for pre-service teachers. So often, pre-service teachers in my classes are able to describe what they would do as a teacher in the classroom, but struggle to consider and articulate both what students would be doing, and more importantly, *what students would be thinking* as they are engaged in learning about Earth Science. One place in the PCK resource guide where this is most visible is in the description of an inquiry investigation that students could conduct about the select topic of interest. In the PCK resource guide I ask the pre-service teachers to describe the inquiry investigation in two ways: first, to give a description of the investigation written from a student's perspective in the classroom – both what she is doing in the investigation, and *what she is thinking* while she is doing it. Second, the pre-service teachers then describe the investigation from a teacher's perspective, describing the directions, questions, prompts and supports that they would give in order to create the space for the students to investigate and learn. A quality evaluation of this part of the PCK resource guide indicates that pre-service teachers are able to distinguish between teacher instruction and student learning, and recognize that telling students what to do and what to know does not equate to student learning and understanding. This perspective is applied to all aspects of the PCK resource guide in the final evaluation.

DISCUSSION

The Earth Science methods course that I have described here is one approach for preparing future Earth Science teachers with the knowledge and skills needed to effectively instruct and support students in learning about important Earth processes, structures, and phenomena. In taking a pedagogical content knowledge approach to the design of the class, the resulting course focuses not as much on Earth Science content itself, but rather on the *learning* of Earth Science. This is an important distinction from straight science content classes. While content understanding is undeniably important, solely being an expert in a disciplinary field is insufficient for becoming an effective teacher (Shulman, 1986). Rather, it is important for pre-service teachers to develop the tools, strategies and perspectives that can foster their own pedagogical content knowledge. This Earth Science methods course is designed to accomplish this particular goal.

One of the more effective ways I have found to develop pre-service teachers' pedagogical content knowledge is to encourage and support them to think about understanding Earth Science concepts from the perspective of the learners in their future classrooms. This means more than just asking them to put on a "student hat" and do the lessons and lab activities as pupils. Rather, it is about asking them to think hard about what students are *thinking* about during these lessons: how they would perceive the goals, how they may interpret the task, and the range of prior knowledge and real-world experiences that they would bring and apply to the lesson. By repeatedly engaging with this type of cognitive perspective-taking, my pre-service teachers develop a greater awareness of how their instruction, resources, and teaching strategies interact with students' meaning-making of Earth Science concepts, leading to more robust PCK for Earth Science teaching at the end of the course.

A second challenge for pre-service teachers is the ability to distinguish between classroom activities and legitimate student inquiry investigations in Earth Science. This is particularly challenging because of the nature of Earth Science as a scientific discipline, with its own unique forms of inquiry and evidence that are different from laboratory-based sciences such as chemistry or physics (Kastens & Rivet, 2008). Both field investigations and computer-based modelling are common approaches in Earth science inquiries, with value placed on identifying spatial and temporal patterns and examining interacting systems across scales (National Research Council, 2012; Rivet, 2016). One key strategy to accomplish this goal is not only to provide multiple examples of different types of student Earth Science inquiry that could be accomplished in secondary school classrooms, but for each, to clearly identify and discuss with the class how and why these inquiry experiences are different from a traditional Earth Science lessons or labs. Again, this often involves class discussions about the distinct nature of students' thinking and reasoning explicitly in Earth Science inquiry investigations, and pointing out where and how the teacher's instruction would support that kind of desired thinking and problem solving.

Third, I have as a central tenant to the design of this and all my classes that learning is not a passive act. Learning, whether it is about Earth Science concepts or teaching strategies, is an active and collaborative process (Blumenfeld et al., 1991). Thus in each lesson I aim to have multiple and varied opportunities for my pre-service teachers in the class to discuss, problem-solve, and learn together. I use a variety of different approaches to create these collaborative learning situations, including think-pair-share, jigsaw groups, count-offs, and other grouping strategies. I also almost always provide groups with poster paper and markers and ask them to write down or draw a summary or representation of their discussions to share with the class. The paper and markers gives my pre-service teachers a way to express their ideas in a different medium, allows them to make their ideas visible and public, and helps to keep the groups' discussions productive and on task.

In addition to making my instruction more effective, these instructional strategies around focusing on student thinking, emphasizing inquiry, and supporting collaborative learning are also ones that I encourage my pre-service teachers to integrate and use in their own practice when they become classroom teachers. This kind of active engagement in a subject-specific pre-service teacher education setting is my way of demonstrating that Earth Science instruction should not be about lecture and delivery of content. Even though the Earth itself is many times larger than the size of a single classroom, learning about the Earth and all of its amazing processes and structures can be an engaging, fun, and rewarding process for not only my pre-service teachers, but their future students as well.

As with any instructional endeavour, I reflect continuously on ways in which this learning experience for pre-service teachers could be improved. One of the central challenges is the limited amount of time available for this course, necessitating making difficult choices regarding what areas to emphasize and what to leave out. For instance, while the focus on developing pedagogical content knowledge regarding pre-service teachers' learning in Earth Science is a primary focus of the course I designed, other important aspects of PCK are not as clearly addressed. These include understanding how to select, adapt, and organize quality curriculum materials, as well as develop a range of effective strategies for both formative and summative assessment in the Earth Science classroom. These central features of quality teaching could be incorporated more effectively into the lessons and assignments for the course. Additionally, the Earth Science content goals themselves are not systematically addressed in this course. While justified in the design choices made for the course, it leaves whatever incomplete or inaccurate understandings of Earth Science that pre-service teachers bring into the class largely unchallenged. One approach to addressing this difficulty that I have explored is to teach this course in conjunction with, or as a companion to, a content-focused Earth Science course taught by my colleagues in the Department of Earth and Environmental Sciences at Columbia University. While still in development, this approach may provide an exciting opportunity for pre-service teachers at both the secondary and potentially post-secondary level to develop powerfully integrated understandings that combine Earth Science content and pedagogical expertise.

NOTES

1 By Original Mats Halldin Vectorization: Chabacano (File:Jordens inre.jpg) [GFDL (http://www.gnu.org/copyleft/fdl.html) or CC-BY-SA-3.0 (http://creativecommons.org/licenses/by-sa/3.0/)], via Wikimedia Commons.

2 By USGS (USGS page 'Inside the Earth' [1]) [Public domain], via Wikimedia.

3 Picture 1: By Bkilli1 (Own work) [CC BY-SA 3.0 (http://creativecommons.org/licenses/by-sa/3.0)], via Wikimedia Commons; Picture 2: By NASA [Public domain], via Wikimedia Commons.

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PART III

SYNTHESIS ACROSS CONTEXTS

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13. SCIENCE METHODS COURSES ACROSS CONTEXTS

Implications for Research and Practice

INTRODUCTION

The purpose of this chapter is to synthesise major themes across the eleven chapters, discussing both common features and distinct practices in various contexts. When we conceptualised this book, we wanted to provide some freedom for authors to emphasise what they deemed the most signature and important aspects of their science methods courses. Yet, we also wanted a general structure for the chapters to provide some points of consistency. This led to the development of four major headings; context, planning/course design, classroom practice, and assessment. These headings served as a useful organiser for this final chapter. Below, we discuss each of these components of designing and teaching the secondary science methods course. For each component, we first synthesise the big ideas that cut across the chapters, and then discuss what we consider to be a major feature of that component. We begin with the three components of the science methods course itself – planning, classroom practice, and assessment – and then discuss the role of context and the extent to which there are differences across countries. Last, we discuss tensions for designing and teaching science methods courses, a roadmap for future research and scholarship, and conclude with a discussion of benefits that readers can gain from this international look at science teacher education. In the writing that follows, we use the term 'teacher educator' to refer to instructors and 'teacher' to refer to learners in secondary science methods courses.

PLANNING

The second section of each individual chapter discusses the planning and general course design of the secondary science methods course. The two common elements within this section across chapters included discussions of general goals and aims of the course, and the major topics addressed throughout the course. Regarding goals, while the authors used different terminology and phrasing to describe major aims, we found that there were three big ideas that cut across most chapters. First, teacher educators want teachers to develop knowledge and beliefs as a science educator – to begin to see science teaching as a profession, with a unique set of knowledge,

A. J. Sickel & S. B. Witzig (Eds.), Designing and Teaching the Secondary Science Methods Course, 225–250.

skills, and dispositions to be developed. Second, there was a clear goal throughout the chapters for science teachers to give strong consideration to the learner when designing their science instruction, including the prior knowledge learners bring to science lessons and anticipated difficulties they will have with understanding the natural world. Third, most chapters discussed the need to confront traditional, didactic modes of teaching science with a multitude of approaches and strategies that are more engaging and meaningful for learners. These goals permeate many of the discussions below, and serve as a unifying theme across contexts.

Major Topics

We were interested in examining the content of science methods courses across various contexts. While reading through each chapter, we first generated a list that included 41 topics as exactly described by the authors. We only included topics that were explicitly mentioned as concepts or skills the teacher educators address in the planning of their methods courses. We then engaged in a round of thematic analysis, as we searched for ways to collapse topics into categories, and then categories into major themes. Our purpose in undertaking this exercise was to be able to provide an accessible and comprehensible list of topic themes across contexts to provide the reader the full scope of content discussed in this book. In Table 1, we provide the seven major topic themes, categories associated with each theme, and a relevant example from a particular chapter.

Table 1. Major topic themes, categories, and examples

Topic Theme	*Categories*	*Example*
Science as a discipline	Nature/Philosophy of Science	Teachers develop understandings of scientific reasoning skills, e.g. inductive, deductive (Kang, 2017)
	Nature of specific science discipline	Teachers consider questions related to a biological phenomena (What is it? How has it evolved?) when planning learning sequences (Janssen & Van Driel, 2017)
	Scientific literacy	Teachers consider fundamental aspects of science as a discipline and how that translates to meanings of scientific literacy (Avargil, Spektor-Levy, & Zion, 2017)
Beliefs	Goals and purposes	Teachers consider the various goals and purposes of teaching chemistry (Aydın-Günbatar & Demirdöğen, 2017)
	Teaching and learning science	Teachers consider the role of teacher and student within the 5E model (Sickel, 2017)

Table 1. (Continued)

Topic Theme	*Categories*	*Example*
Curriculum	Big ideas in the curriculum	With consideration of time and curricular goals, teachers learn to articulate the big ideas to be addressed in their lessons (Aydın-Günbatar & Demirdöğen, 2017)
	Sequencing content	Teachers learn to establish a logical sequence of big ideas in their planning (Mavhunga & Rollnick, 2017)
Teaching strategies	General strategies to be applied in science teaching	Teachers organise their teaching with consideration of ordering different pedagogical strategies and what works for the topic – e.g. teacher explanation, whole task, and part task (Janssen & Van Driel, 2017)
	Science-specific strategies	Teachers learn to articulate how teaching inquiry investigations in Earth Science are different from other science disciplines (Rivet, 2017)
Students as learners	Prior knowledge and potential difficulties	Teachers consider likely difficulties students will experience with learning a topic when planning lessons (Postlethwaite & Skinner, 2017)
	Learning theory	Teachers develop knowledge of learning theories articulated by Piaget, Bruner, and Vygotsky (Kang, 2017)
Learning environment	Learning contexts	Teachers study contemporary science education topics, including informal learning environments (Avargil et al., 2017)
	Classroom management	Teachers consider issues associated with classroom management to prepare them for future school teaching experiences (Mavhunga & Rollnick, 2017)
	Teaching diverse populations with consideration of gender issues as well as cultural, ethnic and/or socioeconomic background	Teachers consider how students' prior contexts permeate the biology classroom (Munford, Tavares, Coutinho, & Neves, 2017)
Assessment	Strategies to assess student understanding	Teachers consider strategies to assess students in interdisciplinary STEM learning environments (El-Deghaidy, 2017)
	Developing an assessment plan	Teachers consider a combination of formative and summative assessments for planning a unit of instruction (Witzig, 2017)

Discussion of Topics

As indicated in Table 1, there is a wide range of topics that can be addressed in a science methods course. Particularly striking to us is the close alignment of the topic themes to models of pedagogical content knowledge (PCK) in science education. For example, Magnusson Krajcik, and Borko's (1999) often cited model of PCK includes five major components, all of which are addressed as a theme in Table 1: science teaching orientations (represented as 'beliefs' in the table), knowledge/beliefs of curriculum, knowledge/beliefs of learners, knowledge/beliefs of instructional strategies, and knowledge/beliefs of assessment. In addition, Magnusson et al. (1999) posited that PCK was informed by science teachers' general pedagogical knowledge (related to 'general teaching strategies' in the table), knowledge of context (related to 'learning environment' in the table), and subject matter knowledge (related to 'science as a discipline' in the table). These topic themes are also recognised in Gess-Newsome's (2015) more recent model of PCK, which discusses subject matter, curriculum, learners, pedagogy (including instructional strategies), and assessment as professional knowledge bases, teacher beliefs as amplifies and filters for making sense of knowledge for teaching science, and considerations of the classroom context when constructing and enacting PCK. Thus, as a collective case of international contexts, we see evidence that the construct of PCK is useful for thinking about the major topic themes that can be addressed in science methods courses.

Though the themes in Table 1 are represented at least once across the various chapters, some were represented more often than others. The three themes that were discussed most often include science as a discipline, students as learners, and teaching strategies.

- *Science as a discipline*. Many teacher educators emphasized the importance of providing opportunities for their teachers to understand the nature of science. The nature of science was often addressed early on in the particular course (e.g. Sickel, 2017; Witzig, 2017), or in the first of a series of science methods courses (e.g. Aydın-Günbatar & Demirdöğen, 2017). In some cases, this theme was addressed with explicit attention to 'nature of science' as a construct often discussed in the science education literature (e.g. Aydın-Günbatar & Demirdöğen, 2017 referencing Lederman et al., 2014). In other cases, authors were referencing what it means to work and think scientifically. For example, Sickel (2017) aimed for teachers to reflect on how they were constructing evidence-based explanations during an inquiry experience, and Janssen & Van Driel (2017) provided examples of how teachers were expected to ask critical questions related to the nature of biological phenomena when developing their lessons (see Table 1). At a more fundamental level, Avargil et al. (2017) ask their teachers to consider both the similarities and differences among the life sciences, exact sciences, and social sciences. At the core of these approaches, many teacher educators have given priority for teachers to think about what science is, what it is not, and what that means for teaching the subject to secondary students.

- *Students as learners*. Another common theme to be addressed in the planning of science methods courses included the learning of science. While in some cases this included explicit references to learning theory (e.g. Kang, 2017), the most common category refers to the notion that students bring ideas about scientific phenomena to the classroom, and that this knowledge should be used as a resource for developing learning experiences. As Rivet (2017) explained, teachers must learn to appreciate their role as one who is constantly considering how a secondary student is thinking in the classroom. It was common for teacher educators to provide opportunities for teachers to review literature on specific alternative conceptions for core concepts in the secondary science curriculum (e.g. Mavhunga & Rollnick, 2017; Munford et al., 2017; Rivet, 2017; Sickel, 2017; Witzig, 2017).
- *Teaching strategies*. A significant topic in all chapters included teaching strategies for secondary science classrooms. In some cases, this included general strategies that are often used for any subject – e.g. the inclusion of cooperative learning (Aydın-Günbatar & Demirdöğen, 2017) or project-based learning (Avargil et al., 2017) – though we acknowledge that the application of these strategies to science lessons has distinguishable features from other subjects. There was also a high volume of strategies that have been established in the science education literature for many years – e.g. inquiry investigations / practical work (Mavhunga & Rollnick, 2017; Postlethwaite & Skinner, 2017; Witzig, 2017), field work (Postlethwaite & Skinner, 2017), interdisciplinary approaches (El-Deghaidy, 2017), predict-observe explain (Kang, 2017), argumentation (Aydın-Günbatar & Demirdöğen, 2017), and modelling (Avargil et al., 2017; Witzig, 2017). Thus, exploring a range of pedagogies and how they can be applied to help students develop conceptual understandings and skills was a common emphasis across the chapters.

With regard to professional knowledge bases, it is interesting to note that knowledge of teaching strategies and students as learners was addressed across chapters more often than knowledge of curriculum and assessment. To some extent, this emphasis seems to mirror the empirical literature on science teacher knowledge. For example, a study by Friedrichsen et al. (2009) found that beginning biology teachers tended to draw upon their knowledge of instructional strategies more so than other knowledge bases, and noted that knowledge of assessment and curriculum was relatively limited. Researchers who have sought to understand how both beginning and experienced science teachers integrate their knowledge have found that teachers' PCK connections tend to include knowledge of instructional strategies and student learning more so than knowledge of curriculum or assessment (Aydin, Demirdöğen, Akin, Uzuntiryaki-Kondakci, & Tarken, 2015; Henze, Van Driel, & Verloop, 2008; Park & Chen, 2012). We acknowledge that our analysis of chapters only gives us a snapshot of the methods courses and what the authors chose to highlight in their chapters, and we conjecture that the topics of curriculum and assessment are indeed addressed in most science methods courses. What we do gain from the chapters is a sense of what might be emphasised the most in a particular course, and therefore a useful question for consideration is whether or not curriculum and assessment may need more emphasis in science methods courses to help teachers develop knowledge in those areas.

Focus on Unifying Themes and Frameworks

When looking at how topics were planned and sequenced throughout the science methods courses, one element was readily apparent. It was common for teacher educators to draw upon unifying themes and frameworks, both to map out the course and to help teachers organise their thinking about science teaching. Rooted in 15 years of design research, Janssen and Van Driel (2017) have developed the 'generative toolkit' as a construct to help teachers become adaptive experts with planning science lessons throughout reflective cycles of teaching. Teachers work through various sets of rules and teaching strategies to develop lesson sequences for teaching biology concepts, and have multiple opportunities to move through the cycle. Avargil et al. (2017) draw upon teacher research as a unifying theme throughout their workshops and seminars, sequencing them in a way that slowly builds up teachers' confidence and skills with designing research projects. Other chapters draw upon frameworks to help teachers articulate their professional knowledge for teaching specific topics (Aydın-Günbatar & Demirdöğen, 2017; Mavhunga & Rollnick, 2017). Taking a different approach, Witzig (2017) provides opportunities for teachers to construct their own research-based frameworks to help them develop their goals and aims as science teachers. There are a number of complex topics for teachers to work through in a science methods course, and we see this focus on frameworks and unifying themes as a useful strategy to connect those topics in meaningful ways.

CLASSROOM PRACTICE

The third section of each chapter discussed a signature lesson or learning experience within their science methods course that each author chose to highlight from the myriad of experiences in their courses. With this section, we were interested in identifying the major teaching strategies that teacher educators employ across contexts. We discuss these strategies below.

Major Strategies for Teaching Science Teachers

Similar to our approach with course topics, we made a list of teaching strategies mentioned by the authors as we read each chapter. While a majority of those strategies were identified in the 'classroom practice' section, some of them were found in other portions of the chapter and were included as well. We then found it useful to group the strategies into categories based on their primary purpose. In many cases, purposes were directly identified by the authors, and in other cases we

Table 2. Major teaching strategies and examples grouped by purpose

Purpose	*Strategy*	*Example*
Develop academic knowledge of science education foundations and principles	Lectures	Teachers participate in formal presentations and discussions about the nature of science, the role of practical work in science, use of ICT, and safety in the laboratory (Postlethwaite & Skinner, 2017)
	Read literature	Teachers read about backwards design and K-12 students' understandings of astronomy concepts to address the pedagogical topic of learning goals and discuss in class (Rivet, 2017)
	Asynchronous forums	Teachers participate in an online forum to write out what they learned about teaching science through models after an in-class activity (Avargil et al., 2017)
	Jigsaw	Teachers divide into groups to understand different curricular emphases with respect to the historical development of the national curriculum and then teach each other in different groups (Kang, 2017)
Develop knowledge of content in the curriculum	Support groups	Each teacher runs a seminar on a specific physics topic to help other teachers enhance their content knowledge (Postlethwaite & Skinner, 2017)
	Concept maps	Teachers develop concept maps of a topic to help them understand and organise the major and sub-major concepts associated with the topic (Mavhunga & Rollnick, 2017)
Reveal goals and purposes of teaching science	Interview	Teachers interview each other about a lesson plan to co-construct a goal system and reveal why a lesson is planned with particular activities (Janssen & Van Driel, 2017)
	Card sort	Teachers participate in a card-sort activity to construct their science teaching orientations (Witzig, 2017)
	Reflective discussion	Teachers engage in discussion about why STEAM education is important in the national context (El-Deghaidy, 2017)
Break down instructional practice	Observe and reflect on lesson as learners	Teachers participate in an investigation on photosynthesis and discuss each component of the lesson from the teacher's and learner's perspective (Witzig, 2017)

(*Continued*)

Table 2. (Continued)

Purpose	*Strategy*	*Example*
	Examine classroom discourse	Teachers examine transcripts of science classroom discussions to examine teacher-student interactions and communicative approach (Munford et al., 2017)
	Examine student work	Teachers examine secondary students' answers and submitted work for a science lesson, and consider how that information could inform future practice (Sickel, 2017)
Practice planning	Mapping out plans for teaching	Teachers continuously work to complete content representations as a tool for planning lessons (Mavhunga & Rollnick, 2017)
	Brainstorming/ Generating ideas for teaching	Teachers collectively brainstorm strategies for integrating STEAM disciplines for potential lesson ideas (El-Deghaidy, 2017)
Practice classroom teaching	Micro-teaching	Teachers practice teaching chemistry lessons in class and receive feedback from their peers (Aydın-Günbatar & Demirdöğen, 2017)
	Reflect on lessons taught in schools	Teachers write a reflection on student thinking after teaching a lesson in a secondary school (Munford et al., 2017)

labelled the strategy with a purpose based on considerations of how the strategy was used. The list of strategies can be found in Table 2.

Discussion of Strategies

Out of the six purposes for utilising particular strategies in secondary science methods courses that we identified (Table 2), three were most prominent across contexts. These included 'developing academic knowledge for science education.' 'breaking down instructional practice,' and 'practice planning.'

- *Developing academic knowledge of science education*. Most chapters discussed strategies that had the purpose of developing teachers' knowledge of science education foundations and principles. This included topics related to science education curriculum standards, reforms in science education, and developing professional knowledge bases in science education – e.g. developing knowledge of how and why we use particular instructional strategies or assessment practices in secondary science classrooms. Some courses have a lecture and tutorial structure, in which the lecture is a useful place to discuss foundational elements of science teaching and learning (Mavhunga & Rollnick, 2017; Postlethwaite &

Skinner, 2017). Another strategy mentioned is for teachers to reflect on science education topics in asynchronous forums. These forums allow for teachers to provide considered reflections on a topic, such as a particular scientific practice, read other teachers' reflections and then finally wrestle with the ideas in a later class session (Avargil et al., 2017). Two teacher educators mentioned the use of the jigsaw strategy, which allows teachers to collaboratively investigate a particular topic in one group, such as examining particular textbook representations, and then meet in a new group to share ideas as the expert (Kang, 2017; Rivet, 2017). The most common strategy for this purpose was reading and discussing literature. Many teacher educators noted that reading literature prior to a class session and then discussing it in class was a significant component of their course design (e.g. Kang, 2017; Rivet, 2017; Witzig, 2017). As noted in Table 2, this could include reading articles that discuss students' misconceptions for particular science concepts. However, teacher educators across chapters mentioned several other topics, e.g. curriculum planning (El-Deghaidy, 2017), scientific inquiry (Avargil et al., 2017), and general principles of learning theory (Sickel, 2017). Inherent in this strategy is the goal for teachers to see science education as a field of inquiry unto itself, and to critically examine the collective knowledge that has been generated from years of research, curriculum reform, and sharing ideas about practice in a larger community.

- *Breaking down instructional practice.* Across many chapters, there was an emphasis on breaking down the critical components of instructional practice to help teachers focus on essential features of teaching and learning science, which are often nuanced and can go unnoticed. One strategy for making instructional practice explicit is for the teacher educator to model the teaching of a science lesson with teachers playing the role of secondary students, with reflective discussions embedded (e.g. Aydın-Günbatar & Demirdöğen, 2017; Postlethwaite & Skinner, 2017; Rivet, 2017; Sickel, 2017; Witzig, 2017). The advantage of this strategy is that it provides an experience in which teachers can immediately consider essential features of a teaching strategy aligned to current research or reform efforts. Often, the lesson they are experiencing differs from how they were taught in prior school contexts. Thus, experiencing the lesson as learners can help them develop practical schemes for how a similar strategy could play out in their own classrooms. Moreover, teachers can begin to see the thinking and rationale behind specific instructional decisions, such as exploring a concept before explaining it (Sickel, 2017), selecting a particular representation (Rivet, 2017), facilitating opportunities for students to discuss and revise claims in light of new evidence (Aydın-Günbatar & Demirdöğen, 2017), or linking student tasks to the big conceptual idea (Witzig, 2017). Two chapters discussed the strategy of having teachers examine excerpts of classroom discourse (Munford et al., 2017; Sickel, 2017). In both cases, the purpose was to help teachers make sense of dialogic interactions between the teacher and students, whereby teachers ask particular questions and respond to students in particular ways to develop the science concept together. Sickel (2017) also provides opportunities for teachers to examine authentic secondary student work related to a lesson he modelled in the science methods course. This strategy helped him discuss the importance of reflecting on student work to inform future instructional decisions.

- *Practice planning*. The third common set of strategies related to the purpose of providing teachers opportunities to practice their planning of science learning experiences for secondary students. This included in-class discussion sessions in which teachers considered the criteria that influence the selection of particular representations (Rivet, 2017), how to plan lessons from different learning theory perspectives (Kang, 2017), and how to plan lessons that integrate content across the STEAM disciplines (El-Deghaidy, 2017). In other cases, teachers are asked to map out their ideas using particular frameworks. Janssen and Van Driel (2017) provide opportunities for teachers to build a repertoire of instructional strategies which can then be organised in a particular way for specific lessons. Two chapters discussed opportunities for teachers to progressively complete a PCK content representation (CoRe), adapted from the work of Loughran, Mulhall, and Berry (2004), which serves as a template for teaching particular lessons (Aydın-Günbatar & Demirdöğen, 2017; Mavhunga & Rollnick, 2017). By participating in these activities, the goal was for teachers to begin taking on the role of a science teacher, and think through practical elements of designing science instruction with frameworks or principles to guide the process.

A common theme that cut across both the design of the science methods courses and teaching strategies utilised was a focus on creating a learning environment that was collaborative and supported active learning. This often included small-group and whole-class discussions, which we did not list as a separate teaching strategy because it was embedded in nearly all activities throughout the book. It was often a central feature of the design of the course for teachers to be active participants in every class session, drawing out important principles of science teaching and learning through discussion. It is notable that this was such a clear theme in the chapters, as it points to a common recognition across contexts that science teachers learn to teach as a community of professionals (Dogan, Pringle, & Mesa, 2016; Nilsson, 2014), and this is to be modelled explicitly in the science methods course.

As mentioned above, the teaching strategies in science methods courses were often used to help teachers plan lessons and break down instructional practice. This was typically at the level of one or a series of a few lessons in a secondary science classroom. Yet, there are different grain sizes of planning science instruction, including (but not limited to) one activity within a lesson, a full lesson, an instructional program or unit, a semester or term, to an entire year. Different grain sizes will bring about different considerations for planning. Whereas a teacher needs to think about the specific questions s/he will ask during one activity, s/he needs to consider the sequence of content, the scaffolding of knowledge and skills toward particular assessments, and how to incorporate diverse teaching strategies for a wide range of topics at larger grain sizes. Therefore, we think it is relevant for science teacher educators to consider the extent to which science methods courses could prepare teachers for thinking about curriculum design beyond a few lessons, and the potential benefits of seeing the bigger picture of organising science curriculum. Just as many of the teacher educators utilised a backwards design approach to map out the assessments and learning activities for their methods courses (El-Deghaidy, 2017; Rivet, 2017; Witzig, 2017), it could potentially be helpful for teachers to engage in this process for their secondary science contexts. It is also important to mention that, similar to our review of course topics, the most emphasised teaching strategies focused on helping teachers plan and facilitate instruction more so than develop or engage with assessment practices, a potential gap to be considered in future course designs.

PCK for Teaching Science Teachers

A signature feature of the teaching strategies is that they often demonstrated PCK for teaching science teachers. There are many arguments in the science education literature that the construct of PCK is not only useful to understand knowledge for teaching science, but also knowledge for teaching about science teaching (Abell, Appleton, & Hanuscin, 2010; Abell, Rogers, Hanuscin, Lee, & Gagnon, 2009; Sickel, Banilower, Carlson, & Van Driel, 2015). Just as a secondary student brings prior knowledge about natural world phenomena to their learning of science, the science teacher has developed many ideas about teaching and learning science before beginning a science methods course. Similar to science teacher knowledge, science teacher educators brings to the classroom their own beliefs about teaching science teachers, as well as knowledge of learners, instructional strategies, curriculum, and assessment for teaching topics in a science methods course, with the goal of transforming that knowledge into learning and assessment activities that make science teaching concepts and practices accessible to teachers.

While Table 2 is not an exhaustive list of strategies for teaching science teachers or the purposes of instruction in a science methods course, it highlights the notion that PCK for teaching science teachers is a unique professional knowledge base. Consider, for example, Postlethwaite and Skinner's (2017) description of classroom teaching. The cornerstone of the class activity is the teacher educator modelling the teaching of a lesson on electricity. The discussions that unfold involve some interactions one might observe in a secondary science classroom. Yet, it is not long into the lesson when the complexity increases. The description demonstrates a constant movement of ideas, from asking teachers to think about the physics concepts (major features of a circuit), the ways in which secondary students will think about the physics concepts (referring to research-based student models of circuits such as 'clashing currents'), and the different strategies that can be used to help secondary students make sense of those concepts (demonstrations, practical investigations, concept maps, etc.), all situated within activities for teaching electricity to secondary students. While reading this description, one can imagine it unfolding in the methods classroom, and how the discussion could not unfold in a productive way without developing knowledge of pre-service science teachers as learners, the difficulties they might have with teaching a lesson on electricity, and how to make the teaching of electricity comprehensible to them. We see this description as an illustrative example of PCK for teaching about science teaching.

Evident in many of the authors' selection of instructional strategies was a consideration of the learner, curricular goals, and assessment practices. Munford et al.'s (2017) strategy to have teachers examine excerpts of classroom discourse clearly aligns to a curricular goal that teachers develop understandings about the role of language in learning science. El-Deghaidy's (2017) reflective discussion about why interdisciplinary STEAM education is important in the Egyptian context takes into account that teachers need a safe place to openly discuss their ideas about reform efforts, and the instructor can gain keen insights into the extent to which the teachers are accepting of reforms at the beginning of the course. Mavhunga and Rollnick's (2017) strategy of engaging teachers in a collaborative exercise of articulating topic-specific PCK for the topic of 'particulate nature of matter' is a scaffold for future assessments (in which teachers continually apply the PCK framework to new topics), thereby representing one targeted step of many as teachers steadily develop their knowledge. Thus, we noticed many descriptive examples of integration between instructional strategies and other PCK components across the chapters.

ASSESSMENT

Following the discussion of classroom practice, the fourth section of each chapter discussed a signature assessment strategy used in the secondary science methods course. Below, we discuss the major types of assessments utilised across chapters, and the common feature of scaffolded assessments.

Strategies

When examining various approaches to assessment, we noticed that assessment strategies were not only mentioned in the designated section, but also in the planning/course design sections for most chapters. We therefore discuss assessment strategies as discussed throughout the entirety of the chapters. We compiled a list of assessments explicitly discussed by the authors and grouped them into categories. In Table 3, we present the 10 major types of assessment discussed throughout the chapters.

Discussion of Assessment Strategies

When looking across the assessment practices utilised across the chapters, the most common strategy included lesson/unit plans. Teacher educators are consistently

Table 3. Major assessment types and examples

Type of Assessment	*Examples*
Participation	A component of pre-service teachers' final grade/mark is based on their active participation and contribution to class discussions (Rivet, 2017)
Formative reflection tasks	Teachers discuss and reflect upon a science education article and submit a written post to an online forum that is formally evaluated (Avargil et al., 2017)
Formative planning tasks	Teachers develop a small-scale task to practice designing and planning science instruction, such as constructing and adapting science inquiry experiences for secondary students (Rivet, 2017)
Learner prior knowledge examination	Teachers formally investigate literature related to students' alternative conceptions for a science concept and develop strategies for eliciting students' prior knowledge about a concept (Sickel, 2017)
Articulation of teaching goals	Teachers develop a research-based framework for teaching science, articulating their own goals and purposes (Janssen & Van Driel, 2017; Witzig, 2017)
Lessons and unit plans	Teachers submit detailed plans for lessons and/or instructional units that could be taught in a secondary science context, including CoRes and/or lesson/unit sequences (Aydın-Günbatar & Demirdöğen, 2017; El-Deghaidy, 2017; Mavhunga & Rollnick, 2017; Witzig, 2017)
Micro-teaching	Teachers are assessed on small-scale teaching episodes in which they practice teaching a science/STEAM lesson (Aydın-Günbatar & Demirdöğen, 2017; El-Deghaidy, 2017; Witzig, 2017)
Research report	Teachers participate in a research project to investigate their practice and student outcomes related to a science teaching intervention (Postlethwaite & Skinner, 2017)
Test	Teachers respond to summative test items that ask them to articulate propositional knowledge for teaching science (Kang, 2017)
Portfolio	Teachers assemble a collection of artifacts, e.g. lesson plans, reading responses, and reflections on practicum experiences (Munford et al., 2017)

asking the teachers to draw upon their professional knowledge to plan well-considered learning experiences for their future students. It was typical for each course to have a substantial summative assessment at the conclusion of the course, whether it be a series of lessons (Sickel, 2017), an exam (Kang, 2017), or a research report (Avargil et al., 2017). Across the chapters, we noted teacher educators' attempts to link the assessment to authentic practices of teaching science, whether it include a lesson that could be enacted in a secondary classroom (Aydın-Günbatar & Demirdöğen, 2017), formative tasks that ask teachers to think like a science teacher (Rivet, 2017), or responding to specific scenarios about how students think about science concepts (Kang, 2017; Mavhunga & Rollnick, 2017).

Scaffolded Assessments

Of particular interest to us was the use of scaffolded assessments, which was apparent in many of the chapters. In their 3rd / 4th year science methods course, Mavhunga and Rollnick (2017) scaffold teachers' development of the CoRe by addressing one component each week. Several teacher educators used micro-teaching as an opportunity for teachers to receive feedback on their lessons and make improvements (Aydın-Günbatar & Demirdöğen, 2017; El-Deghaidy, 2017; Witzig, 2017). Rivet (2017) has designed her course to include small-scale assessments that were eventually included in a larger compendium at the conclusion of the semester. Munford et al. (2017) ask their teachers to utilise a portfolio format to generate a multitude of artifacts to demonstrate and reflect on their development as science teachers across several courses in the teacher education program. Such an assessment has great potential to unify central design features across a teacher education program, and facilitate deeper learning for teachers. With all of these examples, teacher educators are designing their learning activities as informal assessment opportunities to build toward a larger summative assessment, representing an essential practice for meaningful learning (Sawyer, 2014).

CONSIDERING THE ROLE OF CONTEXT

After discussing the chapters collectively and looking for themes that cut across, it is important to also consider the role of context in the design of science methods courses. We discuss the role of context below, and address the question of whether or not contextual factors lead to different approaches to course design.

Discussion of Contextual Factors

To varying degrees, authors provided information on their national, regional, and/or university contexts. There were some explicit examples of the relationship between the methods courses and contextual factors. The three primary factors were national

Table 4. Examples of links between contextual factors and methods courses

Contextual Factor	*Link to Methods Course*	*Example*
National history	Challenges in national history denote the importance of improving science teacher education	Poor economic conditions and dissatisfaction with school outcomes has led to the development of interdisciplinary STEM schools and STEAM integration courses in teacher preparation programs (El-Deghaidy, 2017)
National teacher education priorities and policies	Signature framework within methods class aligns to national priorities in policy documents	PCK aligns to teacher qualifications set forth by the National Ministry of Education (Aydın-Günbatar & Demirdöğen, 2017)
Science curriculum standards	Curriculum standards influence selection of science education topics	Focus on teaching socio-scientific issues was in response to New South Wales curriculum, which consists of learning outcomes that naturally align to SSI (Sickel, 2017)

history, national priorities, and teacher education or secondary curriculum standards (see Table 4 for examples).

For some contexts, we can see connections between the national history and certain design features of the methods course. For this factor, authors mostly described a particular aspect of national history that supports the need to emphasise a particular aspect of the methods course. El-Deghaidy (2017) discussed the concerns of economic output in Egypt, and why it is important for teachers to consider this as a rationale for developing their knowledge for teaching interdisciplinary STEAM lessons. As another example, Mavhunga and Rollnick (2017) provided some background on the effects of Apartheid in South Africa, with under-resourced teacher training opportunities in the past and the strong need to improve teachers' content knowledge and pedagogical content knowledge in current teacher education programs. In these cases, the national history provides a background for which the issue of improving science teacher education, and therefore science methods courses, becomes a central effort.

The second contextual factor refers to national priorities and policies. There are several examples of authors discussing national teacher education standards that need to be aligned to the goals of the science methods courses (e.g. Aydın-Günbatar & Demirdöğen, 2017; Sickel, 2017). In Kang's (2017) methods course, she responds to very specific benchmarks that pre-service teachers must meet on a national exam, and therefore addresses a few topics for that specific purpose. In other cases, there was discussion of how a particular framework within the methods course aligns to national policies. Aydın-Günbatar and Demirdöğen (2017), and Mavhunga and Rollnick (2017) both mentioned that their PCK frameworks align with national policies that describe the types of knowledge that teachers are expected to develop. The focus on developing research projects in science methods courses at Bar-Ilan University aligns to the Ministry of Education's framework of 'teachers as learners' (Avargil et al., 2017), and the focus of addressing the theory/practice gap in teacher education discussed by Munford et al. (2017) was in response to a call for educational reform in that context. Thus, we can see that national policies can shape the priorities and frameworks utilised in science methods courses.

The third contextual factor included mentions of secondary curriculum standards. For example, Rivet (2017) prepares science teachers to teach topics that align with a state-wide exam that secondary students must pass in order to graduate. Sickel (2017) discussed his decision to include socio-scientific issues as a topic for the science methods course due to the high number of secondary science standards that naturally align with that construct. In most chapters, authors discussed a focus on teachers learning to teach core concepts from a particular secondary science curriculum, whether state-level or national-level. Science curriculum is an essential consideration for teacher educators, as we are preparing teachers to teach the content and skills listed in the secondary curriculum.

Across Context and Discipline: Do Science Methods Courses Differ Greatly?

Acknowledging the fact that local, state, and national factors can influence science methods courses, a central question for us when conceptualising this book was to examine the extent to which methods courses differ substantially across international contexts. In addition to the national factors stated above, there is a wide range of program structures represented across the chapters. Some of the chapters discuss undergraduate pre-service programs (Aydın-Günbatar & Demirdöğen, 2017; Kang, 2017; Mavhunga & Rollnick, 2017; Munford et al., 2017), whereas others discuss post-graduate pre-service programs (Janssen & Van Driel, 2017; Postlethwaite & Skinner, 2017; Rivet, 2017; Sickel, 2017; Witzig, 2017) or post-graduate in-service programs (Avargil et al., 2017; El-Deghaidy, 2017). Program structures vary in length, with undergraduate programs lasting 4 or 5 years, and post-graduate programs lasting 1 or 2 years. In addition, the chapters vary by type of science methods course (interdisciplinary vs. discipline-specific), and the number of science methods courses. Whereas pre-service teachers take up to four science methods courses at Western Sydney University (Sickel, 2017), they only take one at University of Massachusetts Dartmouth (Witzig, 2017).

Despite all of the various ways to categorise the methods courses into separate groups, we did not identify any meaningful themes based on a particular grouping. Clearly, there are differences in the various course designs, with respect to topics, strategies, and assessments. However, these differences did not seem to represent a particular group. For example, the selection of topics for science methods courses in a post-graduate program did not meaningfully differ from an undergraduate program. Rather, we found that the similarities in approaches to course design were more noticeable than any differences, with respect to the use of overarching frameworks, strategies to help teachers plan and understand instructional practice, and scaffolded assessments. Where this finding is most surprising is the comparison of interdisciplinary and discipline-specific methods courses. One could potentially argue that a discipline-specific course (e.g. biology-specific) provides more opportunities for teachers to focus on specific aspects of that discipline when designing lessons. This was noted in some of the discipline-specific courses. However, more times than not, the activities and topics related to science pedagogy in a similar way to the interdisciplinary courses (e.g. inquiry, modelling, and argumentation) as lessons were described around science content. In most courses, teacher educators use selected content-based topics in the secondary curriculum as a context for teachers to develop their science pedagogy. Whereas these topics would always relate to biology in a biology-specific methods course and could include biology and chemistry topics in an interdisciplinary methods course, the focus on pedagogical skills used in science teaching and learning was quite similar. We do note that the two chemistry-specific methods courses (Aydın-Günbatar & Demirdöğen, 2017; Mavhunga & Rollnick, 2017) had more similarities than the two biology or two physics methods courses, with both giving attention to PCK and the use of CoRes. However, we believe these selections have more to do with the teacher educators' backgrounds and interests in PCK research than the chemistry-specific nature of the methods course.

We conjecture that teacher educators represent a significant influence in the design of methods courses; their own knowledge and beliefs derived from prior teaching experiences (both in K-12 and teacher education settings), examination of science education literature, and/or experiences with research in science teacher education. Knowledge for designing and teaching science methods courses are shaped by other factors, e.g. including specific topics or strategies in response to an educational policy. However, similar to K-12 settings, the teacher educator is the ultimate gatekeeper for what is taught in the science methods classroom. What we see when look across the chapters is a group of science teacher educators who are often drawing from similar sets of literature, and preparing science teachers to facilitate opportunities for their future students to develop scientific practices and knowledge of core concepts to help them understand the natural world.

TENSIONS WITH DESIGNING AND TEACHING SCIENCE METHODS COURSES

As we reviewed each of the four major chapter sections, the challenges associated with designing and teaching secondary science methods courses were readily apparent. We felt these challenges needed to be further articulated, and a useful

Table 5. Continuum of tensions with designing and teaching secondary science methods courses

	Tension Continuum	
Teaching a survey of many topics	⟷	Teaching fewer topics in depth
Developing teachers' general pedagogical knowledge	⟷	Developing teachers' science-specific teacher knowledge
Preparing teachers to teach science content	⟷	Preparing teachers to teach scientific skills and practices
Facilitating teachers' thinking about science pedagogy	⟷	Facilitating teachers' enactment of science pedagogy
An apprenticeship approach to facilitating science teacher development	⟷	A mentorship approach to facilitating science teacher development

frame was to think about them as tensions (Table 5). The construct of tensions in teacher education is not new (e.g. see Berry, 2007). The value in discussing tensions is that they preserve the complexities of a challenge while also framing it in a way that is accessible and comprehensible. Below, we discuss five major tensions that cut across our work. We purposefully do not offer answers to these tensions, but rather articulate them for further consideration.

1. *Teaching a survey of many topics vs. teaching fewer topics in depth*. Looking across chapters, we see a large number of topics that could be addressed in a series of science methods courses in a particular university. A useful and challenging question is this; which topics are the most important and how many of them can we reasonable address? Teacher educators sometimes have a tendency of including too much content within their courses, believing it is their one chance to influence beginning teachers (Feiman-Nemser, 2001). Many educators would likely advocate for learning a few topics in-depth rather than many topics only superficially, based on research supported knowledge that learning a topic in-depth supports the development of metacognition and more meaningful learning (Sawyer, 2014). When planning a science methods course, it is not always easy to eliminate topics. Some universities may only have one science methods course or have fewer general pedagogy courses that support topics we may consider outside the science methods curriculum. Moreover, we are charged with meeting university and accreditation standards, and with preparing teachers for a large range of issues they will experience in their school placements. Often, the science methods course is an introductory look at science teaching, with the purpose of exposing teachers to a range of considerations needed to teach science effectively. This leads to significant challenges with making decisions about what to teach,

and how much time to spend on each topic. These decisions are complex and ultimately lead to teacher educators prioritising certain topics and strategies over others as well leaving out some entirely, even though they may consider them helpful to the development of future science teachers. What is the right balance of teaching a survey of many topics vs. teaching fewer topics in depth?

2. *Developing teachers' general pedagogical knowledge vs. science-specific teacher knowledge*. In a science methods course, a goal is always for teachers to consider some elements of teaching science that are unique to the subject and likely differ from teaching other subjects (e.g. history, mathematics, etc.). Yet, research has shown that PCK potentially develops from more general pedagogical knowledge (Abell, 2007). Often, we are not only attempting to discuss the numerous topics that have a long tradition in literature on science pedagogy (e.g. inquiry, nature of science, developing PCK for core concepts, socio-scientific issues, and/or scientific practices), but also to integrate more general topics that are necessary to understand with the teaching of any subject. Examples of these topics include principles of curriculum design, generating productive classroom discussions, classroom management, integrating information communication technologies (ICTs), making accommodations and adaptations for students with special needs, and considering cultural, ethnic, and socio-economic backgrounds when planning learning experiences. For many teacher education programs, the science methods course is where it all comes together to learn how to plan and enact instruction in the authentic context of a science classroom. From a situated learning perspective (Cobb & Bowers, 1999), it is a fair argument that the more we can integrate multiple aspects of pedagogy into the subject-specific methods course, the more meaningful the learning experience. Yet, a significant barrier to this approach is the amount of time we are able to provide in-depth learning experiences on all of the topics we are trying to address. What is the right balance of general pedagogical knowledge and science-specific pedagogical content knowledge?
3. *Preparing teachers to teach science content vs. teach scientific skills and practices*. Science is not only a body of dynamic and ever-changing knowledge, but also a way of knowing and thinking about the world around us. It is exceedingly common for national and local science standards to articulate curricular goals for K-12 students to not only develop understandings of core concepts that explain the natural world, but also to develop skills with thinking and acting like scientists. The teaching of science content and skills certainly can be taught simultaneously. However, a methods course is a place where selected components of teaching are examined with a closer lens. Just as the teaching of a concept requires unique understandings of the learner (e.g. how to confront alternative conceptions), so too does the teaching of skills/practices (e.g. considering how to help students identify independent or dependent variables when setting up an experiment). Science skills/practices were mentioned in several chapters, yet our examination revealed that the emphasis was often on teaching science content through those practices

rather than developing the practices themselves. To what extent to do we balance these two critical components of science literacy in our preparation of teachers?

4. *Facilitating teachers' thinking about science pedagogy vs. enactment of science pedagogy.* Across the chapters, we see varying degrees of emphasis on thinking about science pedagogy, through readings, group discussions, and participating in example lessons, and enacting pedagogy, through planning sessions and micro-teaching experiences. Situated in the university context, a science methods course is likely influenced by the culture of university coursework, which typically includes a significant amount of reading and writing as a means to learn about and express learnt knowledge. There are valid reasons for asking teachers to construct formalized understandings of topics within the science methods course, and yet it is also the aim of science methods courses to prepare practitioners. To a certain extent, one cannot learn a practice without opportunities to engage with that practice (Schon, 1983). In the traditional model of a teacher education program, teachers get most of their teaching experience during field placements at local schools. However, the science methods course offers a safe space to develop teaching practices in low-risk environments, and engage with reform-based instruction in a positive way. This juxtaposition is another example of a balancing act that science teacher educators must consider, as it seems unhelpful for teachers to only read about and discuss science teaching, or only practice teaching science without exploring connections to the theory. What is the right balance, then, of thinking about vs. enacting science pedagogy?
5. *An apprenticeship vs. mentorship approach to facilitating science teacher development.* Throughout the book, we see examples of teacher educators modelling research-based thinking and practice, whether it involve guidance toward understanding science learning principles through targeted questions during a discussion or modelling a specific instructional strategy in an exemplar lesson. These approaches seem to align with an apprenticeship model of learning, in which the learner develops knowledge and skills through observing and engaging with an expert (Collins, Brown, & Holum, 1991). And yet, there are also descriptions of activities in which teacher educators are encouraging the teacher to develop their own frameworks for teaching, with their own set of instructional choices and rationales. To this end, the teacher educator is acting more as a mentor; someone who has expertise but provides guidance and takes into account a wide range of possibilities (Callan, 2006). Whereas the first approach tends to assume that we can clearly identify 'best practices' in science education and scaffold teachers' development toward an identifiable end-goal, the second approach aligns with a view of teaching in which there are multiple theoretical perspectives, strategies, and decisions that can be 'best,' and must involve the teacher's own unique knowledge, beliefs, and skills. To what extent can we (or should we) balance these approaches to developing science teachers in a methods course?

FUTURE SCHOLARSHIP ON SCIENCE METHODS COURSES

While the purpose of this book was to present the design and teaching of various science methods courses, our examination across chapters led to several questions that need further investigation in order to effectively improve science methods courses in the future. Below, we offer some possible trajectories of research and scholarship on science methods courses that could benefit the field of science teacher education.

1. *Compare the selection of course topics, strategies, and outcomes across contexts*. There are a plethora of studies within science education that focus on particular interventions within science methods courses and the extent to which those interventions contribute to science teacher outcomes (e.g. see chapters within the 'science teacher education' section of the *Handbook of Research on Science Education* – Lederman & Abell, 2014). In many cases, it is reasonable to assume that a particular focus within a methods course (e.g. PCK, modelling, inquiry, or discourse) will lead to enhanced teacher outcomes related to that focus. In the research community, we are often incentivized during the review process to publish studies that have a narrow focus on outcomes. However, one of the most significant challenges of designing a science methods course is to make decisions about the topics and strategies to include and what to leave out. Therefore, we need studies that examine the fuller scope of topics and strategies within science methods courses and how they influence a range of outcomes. We do not advocate this approach to establish an international curriculum for science methods courses, but rather to move the conversation forward about the benefits or drawbacks of focusing on particular goals and outcomes more than others.
2. *Research and examine tensions for teaching science teachers.* As noted above, we see tensions as a useful frame for thinking about designing and teaching science methods courses, as it not only illustrates the complex and challenging nature of preparing science teachers but also provides a platform for asking useful questions. The extent to which we should balance the extremes of these tensions or tilt toward one side more than another would provide helpful insights to science teacher educators.
3. *Study the impacts of science methods courses in conjunction with other program components*. We know that science methods courses are not designed in a vacuum, but rather are part of larger systems. Most notably, the science methods course is part of a teacher education program, which may have unique features. In the various chapters, there were useful examples of science methods courses working in a particular sequence to coordinate with other courses in the teacher education program, be it general pedagogy courses (Postlethwaite & Skinner, 2017) or science content courses (Mavhunga & Rollnick, 2017). What are the affordances for science teachers when they experience programs that have particular integrated designs? Another important question relates to the potential benefits of teachers

experiencing multiple science methods courses, and the types of science methods courses that lead to the most productive outcomes. The work of Luft and colleagues demonstrate that science-specific induction programs led to more positive teaching outcomes related to teaching science through inquiry when compared to general-pedagogy induction programs (Luft et al., 2011). It seems likely that teachers could benefit from more than one science methods course, but this needs further empirical investigation. Also of importance is to examine the benefits of particular program designs in which there are purposeful connections between the science methods courses and school teaching experiences. This connection was apparent in the methods courses described by Janssen and Van Driel (2017) and Munford et al. (2017). Many of the other chapters explicitly discussed the need to build more connections to classrooms as a current area for improvement in their course (e.g. Avargil et al., 2017; El-Deghaidy, 2017; Kang, 2017; Mavhunga & Rollnick, 2017; Sickel, 2017; Witzig, 2017). Issues related to closing the theory/practice gap in teacher education are well-documented (Darling-Hammond, 2014) and therefore continued research that examines the coordination between science methods courses and classroom experiences is warranted.

4. *Examine specific examples of PCK for teaching science teachers*. As discussed above, we see helpful examples of PCK for teaching science teachers throughout this book. We adhere to a conception of PCK that is both personally and socially constructed by science teacher educators. While the development of PCK has been shown to be idiosyncratic to the individual (Aydin et al., 2015), we see great potential in building up collective understandings regarding professional knowledge bases for science teacher educators (e.g. knowledge of instructional strategies for teaching science teachers) and sharing that knowledge in a larger community. It would be helpful to draw upon more research that examines various amalgams of science teacher educators' PCK and how it contributes to teacher learning when designing and teaching science methods courses.
5. *Further articulate innovative course designs, teaching episodes, and assessment practices in science methods courses*. In addition to empirical studies, we need to link what we know from research on science methods courses to specific illustrations of practice. As argued in our introductory chapter, we do not have enough venues to share these illustrations when compared to K-12 science teachers (e.g. practitioner journals and education department websites that post examples of lessons). In typical peer-reviewed research articles, authors discuss particular components or interventions, or make suggestions for improving practices in science methods courses, but often without specific or practical illustrations due to page limits. The logistical elements and practical schemes for teaching science methods course are often left out of the conversation. What do the discussions look like when making sense of science education articles as a class? How should topics be sequenced to maximise learning? We have developed knowledge about discourse for teaching science (e.g. Mortimer & Scott, 2003), but not as much regarding teaching about teaching science. We have

developed knowledge for helping science students develop models for thinking about science concepts (e.g. Windschitl, Thompson, & Braaten, 2008) but not as much about helping teachers develop models for thinking about science teaching. We believe there is much to be gained from more examples of science methods course design and teaching descriptions through higher education practitioner journals, science teacher education organizational websites, and future books and compendiums.

CONCLUDING THOUGHTS: WHY AN INTERNATIONAL COMPARISON

We have examined science methods courses across eleven teacher education contexts and ten different countries. The final question for consideration is this: What do we gain from taking a closer look at the designs of different science methods courses? We feel this comparison is invaluable to the field of science teacher education, for the reasons stated in turn.

First, to our knowledge this book is the first of its kind; one that asked teacher educators to write about a secondary science methods course in detail, making the tacit knowledge of teaching science teachers explicit. While it is not possible to address every aspect of the methods course in one chapter, what each reader can gain from this book is a rare combination of the behind-the-scenes thinking that contributes to course design paired with practical descriptions of learning activities and assessments. Most science educators at universities have some involvement with science methods courses, and we feel this book can be a useful touchstone to reflect on different approaches for designing an entire secondary science methods course.

Second, readers are likely to learn about a particular topic, instructional strategy, or assessment practice that potentially has value in their own teacher education programs. Whether it involve the use of particular representations for teaching Earth Science teachers (Rivet, 2017), a tool for teachers to transform their knowledge learned at university to the classroom context (Postlethwaite & Skinner, 2017) or strategies for scaffolding teachers' research projects (Avargil et al., 2017), there are practical descriptions of specific topics and activities that will be of use to science teacher educators. Certainly, after examining the chapters, we have learned about strategies and assessments that we are already considering for inclusion in our own methods courses. We feel any teacher educator reading this book will have a similar experience.

Third, as businesses, economies, and politics are becoming more globalised, so too is education. In the field of science education, curriculum materials and research are not just published for one national context, but instead are becoming more and more accessible to a wide range of contexts. Though there will always be specific needs of any local, state, or national context, there are many educational goals that bind us together. We surmise that most science educators are pursuing efforts that contribute to a more scientifically literate citizenry, with more students actively engaged with real-world dilemmas that draw upon scientific understandings, and more students who are excited and interested in pursuing science-related careers. This international comparison provides a platform to understand how teacher educators are responding to needs in their context, which in many cases, relates to particular needs in other contexts. It is notable that some of the authors in this book have teacher education experiences in more than one country. This comparison allows us to start generating an international discussion of preparing science teachers, and thus also developing a community of international science teacher educators.

In conclusion, we feel this book has accomplished our original aims. We have 'lifted the rock' and can now see how science teacher educators are designing and teaching their secondary science methods courses. We see exciting examples of how science methods courses can be a transformative experience for teachers as they learn to teach science in ways that facilitate authentic practices and active thinking. Our examination of these courses does not represent a destination. Rather, we feel the conversation is just beginning. We look forward to participating in future conversations, and hope this book provides a spark for other science teacher educators to share their professional knowledge for designing and teaching secondary science methods courses.

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