The improvement of science education is a common goal worldwide. Countries not only seek to increase the number of individuals pursuing careers in science, but to improve scientific literacy among the general population. As the teacher is one of the greatest influences on student learning, a focus on the preparation of science teachers is essential in achieving these outcomes. A critical component of science teacher education is the methods course, where pedagogy and content coalesce. It is here that future science teachers begin to focus simultaneously on the knowledge, dispositions and skills for teaching secondary science in meaningful and effective ways. This book provides a comparison of secondary science methods courses from teacher education programs all over the world. Each chapter provides detailed descriptions of the national context, course design, teaching strategies, and assessments used within a particular science methods course, and is written by teacher educators who actively research science teacher education. The final chapter provides a synthesis of common themes and unique features across contexts, and offers directions for future research on science methods courses. This book offers a unique combination of ‘behind the scenes’ thinking for secondary science methods course designs along with practical teaching and assessment strategies, and will be a useful resource for teacher educators in a variety of international contexts.
Designing and Teaching the Secondary Science Methods Course
Designing and Teaching the Secondary Science Methods Course

An International Perspective

Edited by

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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
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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’
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 from 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 for the reporting of innovative practices and the design of science method courses and wanted to include authors from each continent of the World 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.

**Structure 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

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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 pre-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 education conferences such as the NARST (https://www.narst.org/) and ASTE (http://theaste.org/).

2 Each continent is represented except for Antarctica.

REFERENCES


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PART I
INTERDISCIPLINARY SCIENCE
METHODS COURSES
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).
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 master’s-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
A. J. SICKEL

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>
<thead>
<tr>
<th>Week</th>
<th>5E Unit as course organizer</th>
<th>Content: Science education topics</th>
<th>Content: Core Learning Principles – Prior knowledge (PK), Big ideas (BI), Collaboration (C), Formative assessment (FA)</th>
<th>Australian teacher education standards</th>
<th>Assessment</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>Engage Lesson planning task – how do you design science instruction?</td>
<td>Nature of Science What is science to you? Students’ Prior Knowledge How can you diagnose prior knowledge?</td>
<td>#1: Know students and how they learn</td>
<td>Begin developing interview protocol; distinguish between phenomenon and concept</td>
<td></td>
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<tr>
<td>2</td>
<td>Explore and Explain Participate in Engage, Explore, and Explain phase of 5E unit on natural selection; Identify key actions/roles</td>
<td>Preconceptions Explore commonly held alternative conceptions Formative Assessment Review types of formative assessment</td>
<td>Learners’ Perspective... PK: Pre-service teachers have different ideas about natural selection C: Pre-service teachers complete activity together</td>
<td>#1: Know students and how they learn</td>
<td>Peer-review of interview questions</td>
</tr>
<tr>
<td>3</td>
<td>Explore and Explain Participate in Elaborate and Evaluate phase of 5E unit; Identify key actions/roles</td>
<td>Lesson Planning: Reflect on natural selection lesson plan; Discuss ‘connecting prior knowledge to new experiences’</td>
<td>C: Pre-service teachers complete the elaborate activity together BI: Pre-service teachers construct components of natural selection</td>
<td>#2: Know the content and how to teach it</td>
<td>Peer-review of diagnostic assessment</td>
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<tr>
<th>Week</th>
<th>5E Unit as course organizer</th>
<th>Content: Science education topics</th>
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<th>Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td><strong>Explore and Explain</strong></td>
<td>Participate in abbreviated 5E unit on heat/temp – discuss safety with science experiments</td>
<td><strong>Sequencing Science Instruction</strong> Reflect on 5E model <strong>Working Scientifically</strong> Connect activities to features of inquiry</td>
<td><strong>FA</strong>: Pre-service teachers learn that they were being assessed throughout the 5E model</td>
<td>#2: Know the content and how to teach it #4: Create and maintain supportive and safe learning environments Peer review of exploratory activity</td>
</tr>
<tr>
<td>5</td>
<td><strong>Explain</strong></td>
<td>Reflect on 5E units and formalize definition of 5E model</td>
<td><strong>Teacher/Student Discourse During Lessons</strong> Explore questioning and feedback during lessons <strong>Nature of Science</strong> Revisit pre-service teachers’ ideas about scientific work</td>
<td><strong>Teachers’ Perspective</strong>... PK: Examine how teacher elicits what students already know BI: Examine how to scaffold core ideas C: Examine strategies for collaborative discourse</td>
<td>#3: Plan for and implement effective teaching and learning Assignment 1 Due • Interview • Synthesis of preconceptions • Diagnostic assessment and exploratory activity</td>
</tr>
<tr>
<td>6</td>
<td><strong>Elaborate</strong></td>
<td>Apply understandings of each 5E lesson phase to different teaching strategies; Discuss how socio-scientific issues can be taught through the 5E model</td>
<td><strong>Science Teaching Strategies</strong> Explore different teaching and assessment strategies <strong>Socio-Scientific Issues</strong> Introduce SSI; Examine connections between SSI and secondary curriculum</td>
<td><strong>BI</strong>: Examine how different 5E units focus on core ideas C: Examine strategies for collaborative student work during 5E activities <strong>FA</strong>: Examine opportunities to assess understanding throughout 5E units</td>
<td>#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</td>
</tr>
<tr>
<td>Week</td>
<td>Activity</td>
<td>Topic</td>
<td>Additional Notes</td>
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<td>7</td>
<td>Elaborate</td>
<td>Socio-Scientific Issues</td>
<td>Present examples of SSI and how to incorporate them into a 5E unit. Continue discussion of core learning principles from weeks 5 &amp; 6. #3: Plan for and implement effective teaching and learning. Peer feedback on lesson plans for 5E unit.</td>
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<td>8</td>
<td>Elaborate</td>
<td>Designing Science Teaching Materials</td>
<td>Work on developing your own 5E unit. 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.</td>
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<tr>
<td>9</td>
<td>Evaluate</td>
<td>PCK in Science Education Teacher Educator’s Perspective...</td>
<td>Revisit lesson planning task from week 1; Reflect on course design as one 5E unit. Link developed knowledge to PCK. 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.</td>
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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
THE 5E MODEL AS A FRAMEWORK FOR FACILITATING

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 exemplary 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 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?
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
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
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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.

REFERENCES


THE 5E MODEL AS A FRAMEWORK FOR FACILITATING


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