Chapter 6
Subject-Specific Demands of Teaching: Implications for Out-of-Field Teachers

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Abstract This chapter provides a framework for thinking about the subject-specific nature of teaching in terms of the knowledge, modes of inquiry and discursive practices that delineate one subject from another in the traditional school curriculum. The chapter will explore how these disciplinary traits are translated into teaching as curriculum, knowledge and pedagogy, and how this subject-specificity of teaching is juxtaposed against the more generic aspects of teaching. The chapter explores the idea that if a teacher's expertise can be situated within a field, then they can also be positioned out-of-field. Implications for teaching out-of-field are discussed in terms of the subject-specific knowledge, processes and skills, and the difficulties associated with teacher practice. English and Australian illustrations of teacher practices from in-field and out-of-field situations are provided, in particular highlighting the demands of moving across subject boundaries. Cross-fertilisation is especially evident when subjects are integrated, therefore, the issues associated with integrated curriculum are discussed where the traditional subject boundaries are being challenged as schools are reorganised to integrate subjects through, for example, STEM teaching, or holistic curriculum designs.

Keywords Subject-specific knowledge for teaching · Modes of inquiry
Subject boundaries · Generic descriptions of pedagogy

6.1 Introduction

This chapter entices the reader into thinking about the subject-specific nature of teaching in terms of the knowledge, modes of inquiry and disciplinary practices

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that delineate one subject from another in traditional school curriculum, and the implications that this traditional carving up of the curriculum (and therefore the task of teaching) can have for teachers teaching subjects without the associated specialisation. This analysis of how qualification matches teaching allocated becomes imperative to consider when the traditional subject-oriented approach to school curriculum is challenged by alternative models of curricular and pedagogical design. Such a challenge comes from the science, technology, engineering and mathematics (STEM) phenomenon, where the economic and political pressure to align educational outcomes with a changing workforce is positioning interdisciplinary thinking, and 'soft skills' (Australian Government 2011; West 2012) such as team work, communication, critical and flexible thinking and creativity, as central to a skill set for the twenty-first century. Utilitarian purposes of schooling take precedence under such regimes, and as a result, teachers face a potential breaking down of the STEM subject boundaries; subjects which have thus far created a 'space' for teachers to situate themselves in and a 'culture' to belong to, in accordance with their disciplinary background and training. Interdisciplinary groups of subjects, such as STEM, and with the arts as STEAM, are emerging and being privileged though curriculum innovation (e.g. Kipperman and Sanders 2007), new teacher qualifications, and even new school infrastructure, such as STEM education centres or facilities in schools. Integration of subjects, as echoes of the integration of the 1960s and other eras (LaPorte and Sanders 1995; Yager 1996), is breaking with traditional curriculum and giving voice to more marginalised subjects such as technology (design and computer technologies) and engineering (which in many countries, such as Australia, is not even included in the mainstream school curriculum). This proliferation of STEM globally, as well as other non-traditional ways of packaging the curriculum, such as through the phenomenon-based approach described in Finland's national curriculum framework, challenge the idea that school is about learning within distinct knowledge and skill sets as defined by the discipline and then translated into the school subjects.

The implication of these changes is that teachers are likely to be faced with developing and implementing new curriculums that may fall outside of their areas of specialisation. The notion of teacher as 'out-of-field' may in fact become a natural part of what it means to be a teacher. A danger associated with this move is that teachers who are teaching content that they are not familiar with can fail to give rigorous attention to the disciplinary knowledge and skills. Before relinquishing the notion of subject teacher, it is important to give serious attention to the subject-specific nature of teaching, both in terms of how the subjects provide meaningful focal points around which teachers develop a sense of identity, belonging, support and collaboration, as well as meaningful teaching and learning practices that are identifiably associated with that subject. For the out-of-field teacher, coming to understand the subjects' content and teaching approaches is only part of their journey of learning to teach the subject.

In this chapter, we examine the subject-specific nature of teaching, beginning with a brief historical account of how school subjects evolved over time. While contemporary schools may still teach through subjects, there remains some debate over what should constitute school content and teaching approaches and the relationship of the subject to its corresponding disciplines. Such debates are illustrated through the case of mathematics as a school subject, where we discuss the relationship between school mathematics and the corresponding academic disciplines.

The evolution of the school subjects imposes demands on teachers and the subject-specific knowledge base for teaching needed by specialist teachers. The implicit assumption is that preparation of teachers as subject specialists is a way of ensuring that school-based curriculum development and delivery is informed by a background of knowledge of disciplinary practices and an appreciation for how the disciplines can be used in answering important societal, political, personal, economic and philosophical questions of life. The basic assumptions underpinning mathematics and science subjects (Hobbs 2012) are discussed in order to explore how the nature of curriculum and activity place subject-specific demands on teachers. Despite this subject-specificity, scholarly debates have lead to a number of trends in education that frame education and teaching in generic terms, thereby at times sidelining the role of the subject in shaping pedagogy.

But what are the implications of having a subject-oriented approach for the preparation and support of 'out-of-field' teachers? Can teachers learn to teach the subject despite not being formally specialised in an area? Research has shown that learning to teach a subject without the necessary background in either the content or the teaching approaches is not unproblematic and therefore requires focused re-training (Crisan and Rodd 2014) and an appreciation of the fact that it can actually be quite difficult to teach out-of-field (du Plessis et al. 2015; Hobbs 2013). This chapter therefore also explores how enculturation into the disciplinary practices and subject culture of out-of-field teachers is possible over time, while considering the challenges associated with crossing boundaries for out-of-field mathematics and science teachers.

6.2 A Brief Historical Account of School Subjects: What Is the 'Field' of a Subject Teacher

Secondary schooling in Australia and England, for example is based on a departmental model. Teaching occurs through subjects, and teachers usually refer to themselves as teachers of specific subject areas. Historically, subject specialisation developed in American education system between the late 1800s and early 1900 (Hargreaves 1994), resulting in the 'emergence and institutionalisation of the academic department' (Siskin 1994, p. 38) in high schools. Siskin suggests that this ready acceptance was because high schools were a relatively recent phenomenon during these discussions and the form they would take was still unclear. Departmentalisation remains one of the main differences between primary and secondary education in Australia and England.

By the 1930s, subjects were firmly grounded in high schools, established through a top-down approach from academic institutions (Siskin 1994). According to Goodson (1993), the subject begins with the creation of an intellectual discipline by scholars, normally working in a university, which is then 'translated' for use as a subject in schools. An academic school subject thus emerges out of a field of knowledge that provides for the subject inputs and general direction. This intrinsic relationship between academia and the development of school curriculum persists today to the extent that 'upper secondary requirements are largely determined by the requirements for university entry with inevitable consequences for the lower secondary curriculum' (Dorfler and McLone 1986).

Teaching became increasingly professionalised as teacher training gradually moved from the school to the universities where the subject specialists were located. Disciplinary boundaries became linked to state certificates of college degrees (Siskin 1994). With the establishment of specialised subject areas, secondary teachers increasingly came to see themselves as part of a 'subject community', and tended to separate themselves from each other (Goodson 1993). Curriculum development became overtly subject-centred to the extent that, in America, concerns were expressed through The Norwood Report of 1943 (quoted in Goodson 1993) that 'subjects seem to have built themselves vested interests and rights of their own' (Goodson 1993, p. 31).

Over the years, the term 'subject' has been applied at a number of levels: as a school examination category, a title for a degree or training course, and as a department within a school. Goodson (1993), claims that the

> "subject" is the major reference point in the work of the contemporary secondary school: the information and knowledge transmitted in schools is formally selected and organised through subjects. The teacher is identified by the pupils and relates to them mainly through her or his subject specialisation. (p. 31)

Departments act as more than administrative units (Siskin 1994); they also serve as the primary site for social interaction, professional identity and community, they represent strong boundaries dividing the school and they influence decisions and shape the actions of individual teachers. According to Siskin, these departments are distinguishable and determined by 'realms of knowledge' (p. 5). These realms of knowledge are more than just adjectives or labels for organising the school, 'these subjects give departments their very reason for being' (p. 153). The knowledge is recognisable so that understood differences between realms of knowledge construct boundaries that draw people together around a common interest. Therefore, subject departments

> are not just smaller pieces of the same social environment or bureaucratic labels, but worlds of their own with their own "ethnocentric way of looking at" things. They are sites where a distinct group of people come together, and together share in and reinforce the distinctive agreements on perspectives, rules, and norms which make up subject cultures and communities. (Siskin 1994 p. 181)

A teacher's identity and work, according to van Manen (1982), are organically bound up in what teachers know about their subject. Teachers describe themselves as teachers according to what they know:

> to know a particular subject means that I know something in this domain of human knowledge. But to know something does not mean to just know just anything about something. To know

> something is to know what that something is in the way that it is and speaks to us. (van Manen 1982, p. 295)

The subject, the subject matter and personal histories in relation to the subject are defining elements for teachers. This was demonstrated through Little's (1993) research into schools that challenged the traditional school structure around subject departments, where it was found that subject allegiance remained high as teachers used subject expertise for maintaining the status of the subject.

Siskin (1994) also found that teachers tended to talk not only about themselves but also about others in terms of their specific subject area as a way of conveying information about their work. What mattered for teachers involved in Siskin's study was 'not simply *that* they teach, but *what* they teach' (p. 155, emphasis in original). Disciplinary background is revealed through a teacher's choice of words, how they structure an argument and their goals for teaching and learning, and this aspect is developed further in the next section.

6.3 Disciplinary Underpinnings of a Subject: The Case of Mathematics as a School Subject

The academic disciplines of mathematics and science are represented as school subjects; however, the nature of what is represented as the subject does not, and perhaps cannot, necessarily mirror that of the academic version of the discipline. The foundational knowledge of mathematics and science are translated and organised for the purpose of meeting the outcomes of education (Beane 1995), hence the school subject will be a simplified form of the discipline, according to how curriculum designers see fit to present a discipline to pupils.

In mathematics, Siskin (1994) claims that teachers in her US study developed general agreement about 'what counts as knowledge, and how it is organised and produced' (p. 170). Counter to such claims of general agreement, Schoenfeld (2004) states that, as with other subject areas, controversies exist about the epistemological foundations of the mathematics discipline, particularly 'what constitutes "thinking mathematically", which is presumably the goal of mathematics instruction' (p. 243). Variation in the conceptualisation of what should be learned and how it should be taught has sparked curriculum reform and different views of the content and purpose of a curriculum have been put forward. For example, Cuoco et al. (1996) proposed a 'habits of minds curriculum' where 'Much more important than specific mathematical results are the habits of mind used by the people who create those results' (Cuoco et al. 1996, p. 1). Through such a curriculum, pupils would have opportunities to learn how to bring together different aspects of their knowledge and how to apply their mathematical skills in tackling a variety of mathematics situations (routine and non-routine, within and outside mathematics). However, this calls for teaching mathematics for its disciplinary and intellectual value, aimed at providing training to the mind of the learners and developing intellectual habits in them.

Despite these controversies, mathematics has often been and continues to be characterised by incremental learning, 'a slow systematic and progressive movement from the simple to the complex' (Hargreaves 1994, p. 139). Mathematics activities are, therefore, often seen as 'a sequential progression through a series of topics, each of which is a prerequisite to what follows' (Sherin et al. 2004, p. 208). With this as a teaching model, Siskin claims that 'math teachers value testing, placement, and tracking as the means of assigning students to the right rungs during their progress up the ladder' (p. 170). In her US study, Siskin found that tracking was a distinguishing feature of mathematics teachers: where tracking was viewed by mathematics teachers as a means of meeting student learning needs, tracking was viewed by teachers from other subjects as simply 'convoluted' and extraneous.

One of the consequences of having widespread agreement on the content and sequence—what Siskin (1994) calls 'the tight paradigm of mathematics'—is that teachers are able to learn the routines, and thereby follow the same curriculum. In 1986, Dorfler and McLone expressed views congruent with Reys (2001) and Siskin (1994) stating that 'the material content of school mathematics is to a high degree internationally standardised. Deviations from this standard are only minor and depend on the educational system, local traditions and influences and perhaps special local demands' (p. 58). This view to some extent dominates accounts of how subject matter is organised as 'coherent sets of topics' worldwide (National Curriculum Board 2008, p. 2). In the Australian context, the framing paper for the proposed *National Mathematics Curriculum* (National Curriculum Board 2008) acknowledges content variations across the Australian states and territories, but proposed a content structure that is based on 'the most common categorisations of the basic content strands…in the compulsory years: Number, Measurement, Space, Chance and data, and Algebra' (p. 2). While it is only realistic to expect that pupils in schools learn about relatively simpler mathematical concepts and principles than those of the discipline of mathematics, curriculum-related controversies raised by this framing paper relate not to what is taught, but to the nature of the proficiency strand incorporating processes involved in 'working mathematically' (p.8), which is about learning and adopting some of the ways mathematicians do mathematics through discovering patterns, formulating conjectures, making links, abstracting, generalising, presenting convincing arguments, justifying and proving, thus helping students develop a conception of mathematics as an intellectually rewarding discipline.

In the next section, the subject-specific nature of teaching in terms of the knowledge, modes of inquiry and disciplinary practices that delineate one subject from another in traditional school curriculum are considered.

6.4 Becoming and Being a Subject Specialist Teacher: What Does It Entail?

Historically, there has been an implicit assumption that a body of specialised knowledge of academic mathematics and science (usually studied beyond the age of 18 years old) is necessary or useful in order to account for the specific demands of school teaching practice. For example, until recently, in England, prospective mathematics teachers who enrol on a teacher training course were required to have studied a mathematics degree or a degree with some considerable amount of mathematics content. However, what of and in which ways this body of specialised knowledge of academic mathematics is necessary or useful to functioning effectively as a teacher of mathematics at a school level is still under much debate (see Chap. 5). There is strong evidence instead which shows that teachers' ideas about mathematics, mathematics teaching and mathematics learning directly influence their notions about what to teach and how to teach it. Such research shows that teachers' goals for instruction are, to a large extent, a reflection of what they think is important in mathematics and how they think students best learn it (Bransford et al. 2000).

As such, those teachers who perceive mathematics as being about computations are likely to emphasise its place in the school curriculum and likely to argue for traditional methods of instructing children in computation. When taught in this manner, Office for Standards in Education (OfStEd) (2008) found that mathematics appears disjointed and meaningless to many pupils, who tend to 'refer frequently to prompts provided by the teacher about how to carry out a technique, but such methods, memorised without understanding, often later become confused or forgotten, and subsequent learning becomes insecure. Moreover, such an approach fragments the mathematics curriculum' (p. 37).

In contrast, those teachers who have been enculturated into mathematics are more likely (not a certainty) to see their discipline as a web of meanings with ideas that unify arithmetic, algebra, geometry and thus more likely to expect pupils 'to remember methods, rules and facts as well as grasping the underpinning concepts, making connections with earlier learning and other topics, and making sense of the mathematics so that they can use it independently' (OfStEd 2008, p. 5).

The OfStEd report (2008) produced detailed evidence and analysis from inspections of mathematics teaching and put forward a number essential ingredients of effective mathematics teaching: teachers' good mathematical expertise (subject knowledge and subject-specific pedagogy) and teaching that focuses on developing conceptual understanding, while the American National Council of Teachers of Mathematics (2000) identified that one of the distinguishing features of an effective mathematics teacher is having an understanding of the 'big ideas of mathematics and [being] able to represent mathematics as a coherent and connected enterprise' (p. 17).

Many of these issues about appreciation for the complexity and connectedness of mathematics ideas are also evident in science teachers. The case for science teacher preparation is more complex, however, in that the science subject consists of multiple science disciplines in which a science teacher might be trained, or enculturated, into one or two. This limited exposure to the broad spectrum of science disciplines has a number of implications for teachers.

One implication relates to what counts as the 'science' subject. In the lower to middle levels of secondary schooling (ages 12–15), science is taught as a generalist science subject in many countries (such as Australia), while in other countries (such as China), science at this level is taught as the separate disciplines, that is, chemistry, biology, physics and earth sciences. This means that in one country, a biology teacher, for example, may actually be considered out-of-field if they are actually trained in physics; while in another country where a 'generalist' science approach is the norm, the same teacher would be considered in-field. This distinguishing feature of science renders international comparisons difficult.

Another implication is that, because of these differences, the 'subject-specific' nature of teaching is delineated by different criteria. The case could be made that a grounding in any science discipline is adequate preparation to teach any science discipline because of a 'common' scientific method, or at least an appreciation for the role of evidence-based claims when seeking answers to questions of a scientific nature. However, it is worth noting that the modes of inquiry of physics and biology, for example, are sufficiently different to be daunting, at least at first, for a teacher trained in one to be expected to teach the other.

The generalist science teacher, if considered in-field, will have background in one or more science disciplines, and possibly not others; this teacher might be considered a 'native' science teacher who is considered in-field but may feel out-of-field in the science disciplines for which they have limited background, or may even be classified as out-of-field in education systems where science disciplines are taught separately. This is particularly the case for teachers at the senior levels where, in most countries, science is taught as a discipline-based model with specialised science discipline teachers, i.e. the chemistry or physics teacher. Teaching out-of-field at the senior level, even as a 'native' science teacher, can be very difficult because of the depth and complexity of content knowledge required. An example of the 'native' science teacher is Donna, an Australian science (in-field) and mathematics (out-of-field) teacher, who explained that a stronger grounding in biological science due to personal experiences with the subject matter, the discipline and the type of thinking required, manifested as a more intuitive approach to teaching science than mathematics or physics. Donna's coherent and unified picture of the biological sciences stemmed from her experiences of learning biology and working with these science concepts in whale research. Physics, however, was considered as foreign for her as any other subject that had not been encountered in any meaningful way. It was for this reason that her teaching of biology required less planning and research compared to her teaching of physics or mathematics, as stated below:

> I don't have a big mathematics background, so I have to spend a bit of time thinking about what could be available and what I could do; whereas with a science background, I think of things just because I'm experienced in that area. So I suppose it might depend on how much mathematics you've done or what resources you've been exposed to, what you might know of… I do a lot more prep for a topic like physics than I would for chemistry or biology. I'm

> teaching a 9/10 combined class in biology, and I'm finding that, like I do my normal prep but I can just go off in class and say, I did this and I've got this example, and we've been having great class discussions and fun activities. I wouldn't have the confidence doing that with a physics topic. So I might spend a lot more time researching it, I might check a few things with another teacher. But I wouldn't have that flamboyance in a topic that, because I haven't done physics at all, apart from bits and pieces of it.

Of course, enculturation into the disciplinary practices and subject culture is possible over time. This is the case of Sara, a computer science specialist teacher and an 'out-of-field' mathematics teacher who participated on an in-service course aimed at addressing the shortage of mathematics teachers in England, UK (Crisan and Rodd 2017). On such a course Sara had opportunities to revisit and teach the subject matter (school mathematics), leading to the development of her technical fluency of some of the more challenging topics taught at different levels of school education (11–16-year-old pupils). Evidence gathered throughout the course showed that Sara was very determined to improve her subject knowledge and familiarity with the school mathematics topics. As the course progressed, Sara became more focused on the learning and doing of mathematics compared with her initial central concern on how to teach a specific mathematical topic. Her lesson planning provided evidence of her consideration for the interconnectedness of the mathematics topics and links with previously taught topics, just as modelled and promoted by the in-service course, providing a strong evidence of her enculturation into the mathematics teacher community.

However, enculturation of the out-of-field teacher often reflects school versions of the discipline; teacher beliefs associated with these versions of mathematics can be very varied (Beswick 2007). This enculturation, therefore, centres on the school subject culture; the subject-specific nature of teaching becomes consolidated, recognisable and describable when exploring the basic assumptions underpinning teaching practices common to the subject culture.

6.5 Subject Pedagogies, Basic Assumptions and Subject Culture: A Case Study from Australia

'Subject culture' refers to the traditions of practice, beliefs, purposes and behaviours associated with a subject. Schwab (1969) states that a complex culture, such as a subject culture, requires both *diversity* and *unity* when conceiving of the tasks of teaching and learning. Unity as common goals amongst teachers within the subject area is important in establishing 'shared traditions, shared experience, shared problems, values and idiom' (p. 198). This unity makes the subject identifiable. Drawing from Organisational Theory, subject culture is underpinned by patterns of 'shared basic assumptions that the group learned as it solved its problems of external adaptation and internal integration' (Schein 1992, p. 12). Basic assumptions are derived from the previous experiences of the individual and consist of perceptions of the nature of people and objects in the work environment. According to Schein (1992), the essence of a group's culture is its pattern of shared taken-for-granted basic assumptions. Schein likens these basic assumptions to Argyris and Schön's (1974) theories-in-use that prescribe how to act, think and feel about things, and that operate as 'unwritten scripts' for members of the group. These scripts internalise a routinised approach to performance on the job: 'Potential courses of action are evaluated in terms of internalized socially constructed theories-in-use' (Schein 1992). Like theories-in-use, basic assumptions are internalised perceptions of the world, objects, ideas and how to relate with others.

In the teaching context, enculturation involves a lifetime of experiences of learning, practising and teaching the subject. If the 'group' refers to all science and mathematics teachers across all schools, then subject culture refers to those shared basic assumptions that govern the dominance of certain 'subject paradigms' (what should be taught) and 'subject pedagogies' (how this should be taught) (Ball and Lacey 1980). These basic assumptions act as signposts and guidelines for teaching and learning the subject.

A study by Darby (2010) explored the basic assumptions of two aspects of the subject cultures of mathematics and science in Australia that appeared to be central for the participating teachers in shaping pedagogy: content organisation and hands-on activities. In this study, six teachers from three schools were interviewed and their teaching observed during two teaching sequences. A thematic analysis showed that, while the nature of the subject matter and its organisation may be unique to any subject and likely to determine teaching practices (Stodolsky 1988; Stodolsky and Grossman 1995), the nature of the curriculum organisation had implications for mathematics teachers in ways that were more significant in shaping pedagogy than for the science teachers. Student support was a central pedagogical imperative that arose out of a highly sequential curriculum where mathematics anxiety and 'filling the gaps' is part of the teaching imperative; for example, one teacher quoted 'I want them to enjoy mathematics. Because mathematics is a threatening subject, it is so threatening because it is so sequential'. Curriculum content organisation was seen to have an immediate and critical role in shaping the practices of the mathematics teacher because of the demand that the nature of the content, the progressive nature of student learning and the traditions of status and importance, place on student learning. The shaping effect of the curriculum organisation appeared less central in the minds of the science teachers, who were guided by an imperative to plan units 'that work', that is, units that are age appropriate and that provide opportunities for students to engage with science concepts at various levels. This comparison arises out of differences in the degree of specificity and sequencing of the subject matter—mathematics to a higher degree than in science.

By comparison, Darby found that in science, teachers showed a firmer commitment to students experiencing natural phenomena. The teachers relied on such experiences to engage students at an aesthetic and motivational level, as well as at a deeper conceptual level. In mathematics, while teachers considered practical experiences to be beneficial for learning, teachers were resistant to their use to some degree due to practical issues that arose as a result of their experience of a traditional commitment within the subject culture to a skills and process based, tightly structured curriculum. Whether a teacher incorporated practical or activity-based experiences in mathematics and science was not simply a matter of having a filing cabinet full of activities, but required an awareness of the purpose and nature of the types of activities appropriate for the subject. It also requires a particular epistemological stance, which is underpinned by a web of beliefs, knowledge and experiences that provides some logic to the pedagogical decisions that are made by a teacher.

The basic assumptions underpinning these positions on these aspects of teaching are outlined in Tables 6.1 and 6.2. Darby used Schwab's (1969) commonplaces of schooling—subject matter, student, teacher and milieu—as the framework for constructing these basic assumptions. These basic assumptions were developed to expound the relationship between the structure of the subject matter and the pedagogy of these teachers, as well as the epistemological, pedagogical and cultural demands associated with curriculum content organisation (Table 6.1) and hands-on activity (Table 6.2). The perceived learning needs of their students and other broader influences from the cultural milieu factor into these aspects of the subject cultures. The basic assumptions listed in Table 6.1 represent the enacted curriculum as it emerges out of the interface of the students' learning needs in the classroom, teachers' beliefs about what needs to be learned and how this is best made available for students, the imposition of a school system and its expectations and demands associated with different subjects and the nature of the school version of the disciplinary knowledge.

The basic assumptions in Table 6.2 represent teachers' experiences of using hands-on activities when teaching mathematics and science: demands imposed by the subject matter, teachers acting within a context that enables or constrains the use of hands-on activities, and expectations of students and teachers to incorporate such activities in supporting conceptual development.

The cultural expectations captured through the basic assumptions above appear to have a strong influence on practice, and in some senses teachers' pedagogical responses are clear. They represent, at least with respect to these teachers, what was considered central and specific to teaching the subject. Darby describes these common responses subject pedagogies (Ball and Lacey 1980) because there was general agreement about what was central to the teaching task.

In mathematics, a 'pedagogy of support' was seen to predominate: the curriculum was seen to be more sequential than in science and moving to increasing degrees of complexity, and this appears to result in a particular response by the teacher—to make it less threatening for students, and to take the responsibility for student progression as a central part of their role. Of fundamental importance is that students are given the best opportunity to be successful in the subject, therefore, support for learning dominated these teachers' approach to teaching and learning. A pedagogical imperative to support students in their learning is, therefore, fundamental to mathematics teachers, both at the relational level where teachers make themselves available, and at a cognitive level where teachers support the development of optimism (Williams 2005) by judiciously offering support for problem solving.

In science, Darby (2010) described a reliance on a 'pedagogy of engagement' where the artefacts of science and natural phenomena are used to engage students with science ideas and ways of thinking. In order to understand how a Pedagogy of Engagement emerges in science, it is important to understand the relative importance

Table 6.1 Subject differences in the basic assumptions relating to curriculum content organisation

	Science	Mathematics
Subject matter	Basic Assumption 1: Junior school science subject matter is organised in topics that are relatively discrete, but there is some sequencing of ideas within the disciplines of science. Topics tend to be iterative	Basic Assumption 1: Junior school mathematics subject matter is organised as a carefully sculpted sequence of skills/processes and concepts, moving to greater degrees of abstraction and complexity
Students	Basic Assumption 2: Missing science content at the junior level has limited bearing on future success with science learning. Students' willingness to engage with future learning experiences, however, is dependent on coherent and suitably targeted content	Basic Assumption 2: Poor skill development can result in insecure foundational understandings, posing a threat to future success. This can result in students feeling threatened by the learning demands of school mathematics
Teacher	Basic Assumption 3: The imperative for the science teacher is to add more pieces to the puzzle for students so that they develop a coherent picture of the knowledge and skills of science, and move them on to more complex concepts	Basic Assumption 3: The imperative for the mathematics teachers is to support students in developing firm foundations to allow them to move successfully to the next level of complexity and abstraction
Milieu	Basic Assumption 4: Science curriculum content is subject to reshuffling, reflecting an acceptance that there is no single trajectory through the subject matter required for students to achieve success in their learning	Basic Assumption 4: Mathematics curriculum content is relatively stable because there is general acceptance about the steps that students should take as they move to greater degrees of complexity. The imperative to ensure student success comes from the importance given to mathematics for school, university and life

Source Darby (2010)

Table 6.2 Subject differences in the basic assumptions relating to hands-on activities

	Science	Mathematics
Subject matter	Basic Assumption 1: Science is seen to be an empirical way of knowing that seeks to explain phenomena and objects that can be readily observed and explained. Often the theory is about the natural phenomena that are being observed and manipulated	Basic Assumption 1: Mathematics is seen as an abstract discipline because the focus is on mathematical objects, structures and relationships that are independent of context rather than tangible objects that can be readily observed. These concepts can be applied to real-life contexts, and understood through real, or concrete, objects
Students	Basic Assumption 2: Students expect to have practical-based learning experiences in science. Such experiences give students the opportunity to think about how theory relates to natural phenomena. The immediacy of the object in science demands engagement with objects so that the provision of hands-on experiences is essential to the learning process	Basic Assumption 2: Students do not necessarily expect to be engaged in hands-on activities in mathematics. An abstract epistemology does not immediately demand concrete representations, although such representations are considered valuable because they can assist in understanding an abstract concept
Teacher	Basic Assumption 3: Teachers are expected to be proficient in planning for, executing and making the most of practical work as part of their teaching repertoire. Teachers rely on these experiences to engage students at multiple levels	Basic Assumption 3: Teachers feel encouraged but not expected to be proficient in providing hands-on experiences. The use of such activities is negotiable and peripheral to the main business of mathematics teaching
Milieu	Basic Assumption 4: Since the objects of science are the focus of instruction, these objects need to be central to the learning experience. Consequently, science is afforded the necessary resources, infrastructure, and personnel to support teaching and learning	Basic Assumption 4: A tradition of commitment to a skills-based curriculum has not prioritised hands-on experiences as part of the learning experience. Infrastructure has been built around teaching approaches that move students through the curriculum, with the textbook as the defining resource

Source Darby (2010)

afforded to the 'cultural artefacts' (from Becher's [1989] theory of academic tribes) of the subject and discipline. For the science teacher and learner, the laboratory, the scientific equipment and the phenomena explored during science lessons are science cultural artefacts. Also, the specialist scientific language, the scientific processes and methods experienced through practical activities are characteristic of science. The defining artefacts represent multiple meanings that are associated with traditional practices of science and science education. Certain expectations are perpetuated. Students expect to do experiments, teachers expect to include practical work as part of their teaching repertoire, and schools expect to have to provide the appropriate cultural grounds and artefacts to enable this practice to take place. The artefacts, both as objects (phenomena and equipment) and practice (practical work), are central to this cultural view of what defines and differentiates science teaching and learning.

The use of the term pedagogy here implies not just an adoption of methods of teaching but a rationale and certain philosophical assumptions. They represent strong discourses that characterised the pedagogical imperatives of the participating teachers. As subject pedagogies, they are recognisable as particular pedagogical practices, underpinned by certain assumptions, and they have a moral dimension in that they are driven by certain pedagogical imperatives that elevate particular beliefs about what constitutes the teaching of one subject above others. These subject pedagogies make the subject teaching identifiably mathematics or science.

What are the consequences of having general agreement about these aspects of teaching? What happens when the prevailing pedagogies resist moves towards alternatives that are underpinned by other basic assumptions? How do these general agreements on what it means to teach the subject affect how teachers negotiate subject boundaries? For example, out-of-field teachers are expected to understand how the curriculum content is organised and how to engage students actively in their learning. Grundy (1994) suggests that in circumstances where teachers are expected to develop a curriculum that explores cross-curricular practices, 'it isn't sufficient that each learning area simply acknowledges the knowledge production processes of other learning areas, each learning area needs to be understood and respected' (p. 13). This need for respect for disciplinary integrity in integrated approaches to curriculum applies also to situations where teachers are teaching a subject with which they are unfamiliar. These teachers may not be as aware of the demands imposed by the subject culture. They may be ill-equipped to filter, respond to or seek alternatives to the subject pedagogies, that is, the 'Pedagogy of Support' and the 'Pedagogy of Engagement', which are underpinned by other basic assumptions about how the subject should be taught.

For example, while teachers in Darby's study identified practical work as critical to engagement, the individual teacher will determine whether practical work is used effectively by creating an environment that fosters deeper levels of engagement, or alternatively rely on the activity to 'hook' students and focus purely on an affective response. An alternative to this reliance on practical work might even be sought through more productive imaginings where students are able to 'make a link, to identify, to engage some part of themselves with something in science' (Lemke 2002, p. 33); this places the emphasis on the mysteries and possibilities that science produces, rather than on objects themselves, or the theory that arises out of scientific investigation.

Similarly, in mathematics, where there is an expectation to support learning in order to prepare students for future learning success, a danger is that this imperative may be interpreted in a way that restricts the learning experience to skills and processes as laid out in textbooks. Another danger is that teaching focuses on coverage rather than depth of understanding, resulting in superficial student learning, difficulties in translating mathematics to real-life contexts, and poor attitudes and self-concept in relation to mathematics. Stacey (2003), however, advocated for 'greater emphasis on explicit mathematical reasoning, deduction, connections and higher-order thinking' (Stacey 2003, p. 122). This agenda calls for teachers to 'create supportive learning environments, to utilise worthwhile mathematical tasks, to manage students' mathematical discourse, and to promote sense making' (Jones 2004).

While there is some flexibility within the traditions to accommodate variation, for a teacher to break away from those traditions to embrace emerging traditions emanating from the research literature requires an appreciation of what is possible within the epistemological and pedagogical constraints of the subject. A number of factors, such as teaching backgrounds, subject commitments and beliefs about teaching and learning, mediate a teacher's capacity to interpret the traditions, and degree of autonomy to challenge or move forward from those traditions.

6.6 Challenging the Role of Subjects and Subject Cultures in Determining Pedagogy: Subject-Specific Versus Generic Descriptions of Pedagogy

While a tradition of subject specialisation in secondary schools has contributed to a tendency to promote pedagogy appropriate for specific areas of content, in recent years, various curriculum models underpinning education systems reflect a rethinking of the purpose and role of the 'subject'. These models are informed by research focused on a contemporary view of the purpose of schooling that has generated, and reported on, a shift in the way pedagogy is conceived, particularly in the middle years of schooling. This section outlines some of the arguments and counterarguments involved in this debate about the integrity of 'the disciplines' as conceptualisations of pedagogy is distanced from the context of the subject.

In 2004, Gardner stated that disciplines are 'the best answers that human beings have been able to give to fundamental questions about who we are, physically, biologically, and socially' (p. 233). They are distinctive in terms of mores, genres, syntax and content, the mastery of which takes time. However, historically, research in teaching and learning has regarded subject matter disciplines in varied ways: 'as the organizing framework for investigation and implementation' (Shulman and Sherin 2004, p. 135); or as secondary to 'generic principles of instruction that could transcend disciplinary boundaries' (Shulman and Sherin 2004, p. 135). The result was that content areas nearly disappeared from research at various points in history.

Since the mid-1980s, research on teacher thinking and teacher knowledge, which recognises the importance of teacher cognition as a means of understanding the teaching process, focused on the complex relationship between subject knowledge and pedagogy (Shulman 1986; Wilson et al. 1987; McNamara 1991; Banks et al. 1999). Shulman (1986) argued that researchers neglected to ask questions about the content of the lessons taught, the questions asked and the explanations offered.

> Where do teachers' explanations come from? How do teachers decide what to teach, how to represent it, how to question students about it, and how to deal with problems of misunderstanding? […] Research on teaching has tended to ignore those issues with respect to teachers. (Shulman 1986, p. 8)

Shulman (1987) attempted to outline the categories of knowledge that teachers must master in order to teach their subject matter. Among the categories, he includes both general pedagogical knowledge and discipline-specific pedagogical knowledge, referred to in literature as 'pedagogical content knowledge' (PCK). Shulman conceptualised this term (PCK) as being an amalgam between content and pedagogy necessary to an understanding of how particular topics, problems and issues are organised, represented and adapted to the diverse interests and abilities of learners. For example, PCK enables teachers to come up with examples, authentic problems and rich applications that enable pupils to see the usefulness of mathematics, the links to other disciplines and the interconnectedness of ideas in mathematics. It also encompasses an understanding of the learning process itself, including an awareness of the conceptions or misconceptions which students may bring to their learning. Shulman (1986, 1987) suggested that discipline-specific pedagogical knowledge is particularly important for teachers who specialise in teaching a particular subject matter, differentiating as such the expert teacher from the content expert. (See Chap. 5 for a deeper discussion of knowledge in relation to teaching out-of-field.)

In the early 2000s in the US, Gardner (2004) saw disciplines as being threatened by 'facts, which are discipline-neutral subject matter, and which serve as just a textbook convenience' (p. 233), and by 'interdisciplinarity, which often ignores and obscures disciplinary differences' (p. 233). These pressures were evident worldwide where interdisciplinary approaches to broad scale and localised curriculum development were being explored through integrated and alternative middle years programmes in the early 2000s, and more recently through the schools' response to the STEM agenda.

What does this shift from tradition mean for science and mathematics education? In a review of subject matter, Shulman and Quinlan (1996) predicted that subject matter would again take prominence in determining school curriculum as the work of scholars in creating the knowledge and of citizens and professional practitioners who use and enjoy the knowledge in the real world play a significant role in defining what counts as subject matter. The social contexts or communities within which the knowledge is discovered and used will become part of the definition of how classrooms are organised for its study. And epistemological questions will finally reach parity with questions of substance in characterising the curriculum. (p. 421)

Shulman and Quinlan's (1996) predictions were not unfounded. There was considerable evidence leading up to 1996 of student dissatisfaction with school, especially with what was being offered in the middle years (Anderman and Maehr 1994; Beane 1990; Sizer 1994). For example, Hill et al. (1993) noted a decline in the engagement of young adolescents in secondary school compared with their engagement at primary school. There was mounting evidence to support a change in direction of curricula and syllabi to recognise the unique needs of middle years students.

The reform in the middle years of schooling in the early 2000s reflected a modified emphasis on subjects where the purpose of the subject matter was as context for delivering an alternative curriculum concerned with 'many of the communicative, expressive, thinking, affective, moral and social experiences which can provide students with impetus to their holistic development as young adults' (Arnold 2000). Arnold stated that middle school curricula and syllabi should 'reflect integrated approaches emanating from collaboration between teachers of different subjects and between the teachers with their students' (p. 4). The New Basics curriculum model trialled in Australian state of Queensland represented such an integrated framework for curriculum, pedagogy and assessment (see Matters [2001] for a review of the New Basics trial), and signalled a move towards generic description of pedagogy. The framework incorporated Productive Pedagogies, derived from Newman's construct of Authentic Pedagogy, and Rich Tasks that allowed students to 'display their understandings, knowledge and skills through performance on trans-disciplinary activities that have an obvious connection to the real world' (Matters 2001, p. 2).

Gardner's (2001) argument for more purposeful education did not promote the integration of subjects but advocated that disciplines should provide the context for in-depth study of an area of content. The pressure to get through the curriculum, he proposed, should be replaced with opportunities to develop a 'rounded, three-dimensional familiarity with a subject' (Gardner 2001, p. 5). The subject matter, therefore, remains the context for teachers' knowledge about teaching and learning, and a tool for drawing out pedagogical knowledge.

According to Shulman and Quinlan's 1996 prediction, 'Much of the educational psychologists' work will involve inquiries into the advantages of different strategies for transforming subject into subject matter' (p. 421). Indeed, Stodolsky (1988) noticed striking differences in patterns of instruction in upper primary classrooms that she considered to be a function of the subject matter. In challenging the assumption that teaching and learning were seen as uniform and consistent, Stodolosky highlighted that teachers arrange instruction differently depending on what they are teaching, and that students respond to instruction differently depending on the structure and demands of the lesson.

Indeed, subject-specific descriptions of pedagogy take into account a subject-specific awareness of content that informs pedagogical decisions. Building on Shulman's (1986) two domains of knowledge, namely SMK and PCK, Ball and her colleagues developed the mathematical knowledge (MKT) framework, where MKT is 'the mathematical knowledge needed to carry out the work of teaching mathematics'(Ball et al. 2008). The MKT framework provides a framework for the discussion of teachers' mathematical knowledge and has been used extensively in informing the development of teacher education programmes and the design of support materials for teachers. Subject-specific teaching strategies are described in terms of when to use them and the degree to which they are deemed useful (Ball et al. 2005). Where pedagogical frameworks or educational policy are described in generic terms, the focus shifts from the knowledge structures, skills, processes and stories of the subject to more general issues, such as student learning, developing relationships and personal development. Also, the teacher's identity shifts from subject specialist to pedagogue. While these shifts in themselves are not necessarily negative outcomes for teachers with strong understanding and content appreciation, for teachers who do not have those passions and positive background experiences to inform their teaching, the aesthetic of the subject can be lost.

Stodolsky and Grossman (1995) claim that the content provides the context for the secondary teacher, not just in terms of the subject matter to be taught, but in the ways teachers think about learning, assessment and their roles as teachers (see also Grossman and Stodolsky 1995; Siskin 1994; Stodolsky 1988). Research has shown that the content places contextual demands on teachers' interpretation and response to a 'generic' imperative to make schooling relevant (Darby-Hobbs 2013). Teachers' beliefs about the value of the subject are bound up in the perceived potential purposes that the content could have for students and themselves.

The specificity of subject teaching is delineated on the basis of content, but the teacher's understanding of how to teach the subject is based on more than content knowledge.

Sullivan (2003) recognises the importance of an aesthetic dimension of teachers' mathematical knowledge, asserting that:

> this knowledge is not just about the formal processes that have traditionally formed the basis of mathematics curriculums in school and universities but the capacity to adapt to new ways of thinking, the curiosity to explore new tools, the orientation to identify and describe patterns and commonalities, the desire to examine global and local issues from a mathematical perspective, and the passion to communicate a mathematical analysis and world view. (p. 3)

Research by Hobbs showed that a teacher's pedagogy is informed by subject matter and passion (Hobbs 2012). A teacher's multiple identities arise out of the interaction between their perceptions of themselves as subject specialist and pedagogue. Their identity can, therefore, be deeply seated in the subject that they teach and have been enculturated into. A mathematics teacher from Hobbs' study, for example, indicated that she thought of herself as a teacher of students rather than a subject specialist; however, her dealings with students were bound up in her awareness of the learning needs of her students that were specific to that subject, that is, a need to support their mathematics learning. Although the welfare of her students was foremost in her mind, the subject-specificity of her pedagogical purpose lies in her awareness of the reasons for these approaches, and what aspects of mathematics she values and expects to expose for her students to respond to (see Ball et al. 2005).

It was, therefore, not possible to think of her teacher identity in a non-subject-related way.

6.7 The Challenges of Crossing Boundaries for Non-specialist Mathematics Teachers: A Case Study of an In-service Course from England

The need to conceptualise pedagogy in subject-informed ways extends to how we conceptualise professional development for in-service teachers. Generic-based professional learning opportunities cater for only part of the teacher's professional needs. Research has shown that teachers in rural or regional settings can feel disenfranchised by professional learning programmes that cater for the needs of the whole school at the expense of subject-related needs (Tytler et al. 2008). Other research shows that the subject matters with regard to teacher support. Subject-specific mentors have been shown to be more effective in US science teacher induction programmes due to the specific support they can give in the areas of instruction, running practical activities, and planning, as well as support to incorporate 'science as inquiry' and the 'nature of science' into their teaching (Luft 2008). Grossman et al. (2004) further highlight the importance of providing external sources of subject-matter expertise when supporting reform efforts. They assert that the extent, and availability, of subject-specific instructional leadership has an effect on the degree to which teachers incorporate reform ideals into their practice: 'how teachers and administrators respond to and implement subject-specific policies will vary considerably, depending largely on their own knowledge of and beliefs about the subject in question' (p. 12).

Negotiating the boundaries between subjects can be difficult for the out-of-field teacher who has limited background and appreciation of what it means to teach the subject. Unfortunately, for some of these out-of-field teachers, there is limited access to people who might be seen as *culture brokers* (Stanley and Brickhouse 2001) who could play an important role in assisting them with their border crossing. The head of department and other subject teachers may assume this role, but some teachers receive little support, particularly in small schools in rural and remote locations where there are no other teachers to participate in subject-specific professional dialogue or where professional development is not readily available or only deals with generic teaching and learning issues (see Tytler et al. 2008).

However, in some countries government policies are responding to the lack of subject-related expertise of some teachers, calling for the provision of subject-related professional development, delivered by highly specialised teacher educators (see Chap. 11 for further analysis of professional development of out-of-field teachers). For example, a recent UK government call requires that all staff directly involved in the development and delivery of training are experienced in delivering high-quality professional development, have a deep understanding of the specialist subject required for high-quality teaching of the subject and understanding how teachers develop this knowledge.

To address the shortage of mathematics teachers in England, UK, serving teachers, qualified in subjects other than mathematics yet teaching secondary mathematics, were eligible to participate in post-initial teacher training subject knowledge enhancement courses commissioned and funded by the Teacher Development Agency (2011). Crisan and Rodd (2011, 2014) found that the participants on such courses (referred to as non-specialists mathematics teacher, the terminology for out-of-filed teachers used in England, UK), all of whom were aware of limitations in their own mathematics subject knowledge at the beginning of the course, towards the end of the course were able to articulate a wider view of the nature of mathematics.

While an understanding of subject matter content knowledge for teachers is necessary, Wilson et al. (1987, p. 105) advised that 'it is not a sufficient condition for being able to teach'. Given that the participants on the course were serving teachers, issues related to how to teach specific mathematics topics arose naturally in their questioning/enquiry and so a prominent feature of the course was also the participants' learning about mathematics pedagogical issues, which were taught by example and discussion of pedagogical implication of teaching specific mathematics topics. At the end of the course, the teachers still lacked fluency with mathematics and were far from having secure subject knowledge. However, the teachers overcame some difficulties they had with mathematics in the past and, by immersing themselves in learning mathematics, they felt more secure and confident in their mathematics and teaching of it. These teachers came to appreciate and understand mathematics, and related to it in a more personal manner. Familiarity with and learning of new mathematics topics on the course increased their confidence in themselves as learners of mathematics.

This experience of learning to teach mathematics out-of-field illustrates that there is no quick-fix re-training to become a mathematics teacher. Experiencing the joy and satisfaction of doing mathematics, beginning to see connecting themes in mathematics and experiencing being a mathematics learner on the course positioned the participants on the trajectory of learning towards a new identity, that of mathematics teachers (Crisan and Rodd 2014). For example, when visiting simplifying algebraic expressions, the participants surprised us with the questions they were asking. The questions were not just about how to get an answer; the teachers were enquiring about: the mathematics vocabulary specific to the topic and the appropriateness of using the mathematical words in other contexts (e.g. coefficient, term, equal, equivalent); the mathematical structure (e.g. in $a + 3b - 2c$, is the last term $-2c$ or $2c$?); and collection of terms (flexibility of interpretation of operations in an algebraic expression: from take away 2c to adding negative 2c). We also observed that these teachers were unpicking a mathematics topic to a greater degree than we observed in graduate or trainee (or pre-service) teachers who were already confident with simplifying algebraic expressions. It could be argued that our non-specialist mathematics teachers were asking these questions because they were lacking the necessary mathematical knowledge; however, their enquiries were evidence of their generic pedagogical knowledge in action where they had the ultimate aim of enhancing their mathematical subject-specific pedagogical knowledge, while at the same time facilitating an awareness of and a deepening of their own understanding of the subject matter under scrutiny. Our non-specialist teachers came on this course with weak subject knowledge, which they consolidated through thinking of questions of pedagogical nature (e.g. how would I teach this?, what if pupils would ask this?).

As the course progressed, we noticed that the non-specialist participants became less preoccupied with how to teach particular mathematical knowledge and more interested in the learning and doing of mathematics. They began to see mathematics in a new light, more than just a set body of knowledge and skills. For example, while on the course, Jessie, a Physical Education (PE) specialist teacher on the in-service course expressed a view of mathematics knowledge as reified items: 'all of a sudden and everything that I've got from pockets of knowledge here and pockets of knowledge there, just all falls into place' (Jessie, interview).

The teachers experienced joy and surprise at noticing connections between different topics, starting to see mathematics in a new light, more than just a set body of knowledge and skills. For example, when looking at the mathematics within the Pascal triangle, the teachers were amazed to discover many mathematics topics they had previously studied 'in the triangle'. 'It's all in there!' exclaimed Matthew in disbelief.

In interviews, in their assignments and in class presentations, the teachers talked about their changing of views of mathematics towards that of more useful or more real: for example, 'Through completing this course I feel I've moved on from viewing mathematics as a pure subject that is learnt in classrooms to seeing mathematics as something that has endless applications' (Nas, final assignment). Just like Nas, Crisan and Rodd (2014) found that by the end of the in-service course, most of the non-specialist mathematics teachers were 'talking the talk' about what it takes to be a mathematics teacher, influenced by the practices promoted by the in-service course. For example, they talked about the interconnectedness of the mathematics topics, links between topics, use of investigative approaches and group work.

Nevertheless, 'talking the talk' did not imply 'walking the walk' as they also found that teachers on an in-service course may seek to belong to a community of mathematics teachers, but lack of mathematical knowledge is reflected in less effective pedagogical choices. This was the case for Eva, a PE specialist and a non-specialist mathematics teacher on such an in-service course, who worked in a school as a teaching assistant. Eva was very well supported by the mathematics department and she used the resources this environment affords for her mathematical development: 'all the mathematics teachers in my school help me get on with mathematics' (post-lesson observation interview). However, when teaching her low prior-attaining 11- and 12-year-old students to work with fractions she restricted instruction to rehearsal of standard rules only. She did not exploit linguistic, diagrammatic or scenario representations, while the downloaded materials were used unadapted and were rather inappropriate, suggesting a restricted subject-specific pedagogical knowledge, hence making a less effective pedagogical choice in her lesson.

Generally, however, Crisan and Rodd (2014) found that the non-specialist mathematics teachers, all of whom enrolled on the in-service courses with an awareness of limitations in own mathematics subject knowledge, were able to articulate a wider view of what mathematics was about towards the end of the course. Ahmed, a non-specialist mathematics teacher with a specialist teaching background in computer science, was almost demanding to be shown how to answer 'types of mathematics questions' in an instrumental way: 'Show us: Step 1, step 2, and so on. Just like in programming'. Towards the end of the course, Ahmed became more adaptable and he too started to experience joy and satisfaction of seeing connecting themes in mathematics and experiencing being a mathematics learner on the course.

Research by Crisan and Rodd (2011, 2014) shows that being learners of mathematics and immersing themselves in doing mathematics have increased their confidence with the subject matter by revisiting and developing their fluency with the school mathematics topics they would be required to teach. Moreover, reflection on their own learning of and doing mathematics nurtured the non-specialists' mathematical awareness by noticing more mathematically and pedagogically, developing thus a subject-specific pedagogy.

Indeed, the need for extensive professional development and support illustrates that some teachers find it difficult to learn to teach a subject effectively. It also illustrates that generic skills are not enough for a subject teacher. How then, can a teacher be expected to teach difficult subjects effectively when they are out-of-field or unspecialised? This question takes on particular importance when the subject boundaries are removed, which appears to be a possible pathway for education into the future.

6.8 What Does the Future Hold?

In many parts of the world, there are shifts towards new ways of conceptualising schools and curriculum, leading to alternative teacher collaboration models, and challenges to the traditional siloed approach to curriculum knowledge. The virulent spread of STEM globally moves towards an automated and therefore changing workforce, and disruptions caused by international comparisons (such as PISA and TIMSS) all put pressure on schools to rethink and rebadge what they teach and how they teach it. As a result, the subject teachers as they currently exist is potentially going to be re-scoped, that is, the scope within which they are expected to operate is likely to expand or at least shift from individual subjects to a more amalgamated, problem-based space. This re-scoping may lead to a blurring of the boundaries that have traditionally delineated the knowledge considered important for education; it may also render some knowledge redundant. In the 1980s, the move towards integration (LaPorte and Sanders 1995), and the Science-Technology-Society (STS) focus of the 1960s and 1970s (Yager 1996), had a similar effect, although the longevity of this agenda was threatened by concerns that the subject disciplinary knowledge and practices were compromised, and pressure to reinstall the traditional subjects prevailed. The recent push for STEM in many countries (such as the United States, United Kingdom, and more recently in Australia) faces similar criticism, with concerns raised about interdisciplinary approaches to STEM leading to superficial treatment of some subjects. McGarr and Lynch (2015) for example raise concerns about the colonisation of technology and engineering spaces by mathematics and science, which have greater power and status because they have more defined subject boundaries, and there are strong rules governing what content is and is not part of the subject. However, other research has found that even mathematics teacher with excellent pedagogical skills and adequate mathematics knowledge actually found it quite difficult to integrate mathematics into STEM programmes (Mousa 2016). Superficiality can also arise because of the limited expertise of the teachers in some of the subjects that they are expected to integrate. To make this work, teacher collaboration models need to ensure specialist knowledge within the teaching team is pooled and out-of-field teachers are supported; also teaching spaces can be opened up and modified to allow for seamless interaction between the in-field and out-of-field teachers as needed. It is important to remember, however, that interdisciplinary teams are typical in the STEM disciplines and industries because of the need for complex solutions to complex real-world problems, so modelling of this type of shared expertise can potentially lead to quite innovative curriculum. For example, teachers of science can work with the mathematics, technology and arts teachers to develop a student project, e.g. a vehicle design that requires student learning in each of the four subjects during the same school term. This approach is quite different to a unit of work taught by one teacher who incorporates both mathematics and science outcomes; in this approach, unless the teacher has a full appreciation of the mathematical and scientific concepts involved they are at risk of giving inadequate treatment to both content areas.

Another example of this interdisciplinary approach comes from Finland, who, since 2016, are ‘trading in teaching by subject (e.g. an hour of history followed by an hour of geometry) in favour of “phenomenon teaching,” or teaching by topic’ (Briggs 2016). The main goal of the reform was to ‘create better prerequisites for successful teaching and for meaningful and enjoyable learning so that students would develop better competences for lifelong learning, active citizenship, and sustainable lifestyle’ (Airaksinen et al. 2017, p. 2). While this reform was met with initial objections by teachers who have spent their careers developing subject-specific teaching expertise, reports show that there is some advancement in student learning outcomes (Briggs 2016). This type of systemic reform of the curriculum requires a reconceptualization of the role, commitments and expertise of the teacher, as well as a move towards learning that is more active and participatory in nature (Airaksinen et al. 2017). Proponents of the model state that ‘At the level of disciplinary experts, there needs to be continuous involvement of real-world users of the disciplines, in addition to reform-minded academics’ (Briggs 2016). Indeed, Airaksinen et al. (2017) highlight that crossing the boundaries within schools will require ‘strengthening of the collaborative, multidisciplinary, and multiprofessional approach, developing the schools as a learning community’ (p. 13), and that teaching competences would need to be re-conceptualised as transversal in nature rather than subject bound.

6.9 Conclusion

The argument in this chapter assumes that the expertise of a (secondary) teacher has, at least in some part, some alignment with the fields of knowledge, ways of knowing and modes of inquiry that they have encountered at university and in their initial teacher education. When 'in-field', their teaching allotment aligns with their specialisations, which, it is assumed, prepares them for teaching the subject content and pedagogy. When allotment does not match this background, the teacher is considered out-of-field. Of course, there are many aspects of a teacher's expertise which can be considered general to teaching and not specific to the subject. However, even seemingly generic knowledge can be understood through the lens of the subject.

Teachers teaching a number of different subjects are expected to understand pedagogical traditions in each subject, including basic assumptions that underpin these traditions and expectations. Out-of-field teachers may be less aware of the demands imposed by the subject culture and may be ill-equipped to appropriately filter, or respond to predominant pedagogies that may not necessarily align with reformist agendas in mathematics or science. Being aware of the demands of the subject can enhance a teacher's ability to seek appropriate alternative practices. This is significant for a number of reasons. First, subject pedagogies within the school have the potential to shape the practice of a novice or out-of-field teacher, particularly if those traditions and practices are deeply rooted in the school subject culture. Teachers who are flexible and embrace innovation and change are more likely to be successful in countering prevailing subject pedagogies that perpetuate traditional and ineffective teaching practices. Second, knowing what works and what does not, and an appreciation for how the subject both affords and limits change is required before a teacher can contribute meaningfully to conversations about curriculum development and innovation.

Having a background in a discipline is likely to equip teachers with the disciplinary knowledge to draw on in their teaching and an appreciation and enthusiasm for the subject that can be transmitted to students, qualities that are often used to define effective teachers (Darby 2005) and potentially lacking for teachers teaching out-of-field (Ingvarson et al. 2004). Other research shows that, while a teacher's practice is dependent on the experiences that the teacher has had with the subject or discipline, these experiences are not necessarily related to exposure at university level. For example, other factors, such as career trajectory (Siskin 1994) and professional development (Crisan and Rodd 2014; Tytler et al. 1999), have been found to be cogent in determining how teachers approach teaching and learning. These research outcomes highlight the importance of paying attention to teachers' experiences of the subject they are teaching. Evident also is an assumption that teachers can be enculturated, hence inducted into the culture of a subject through their experiences, and that, with further training, teachers can improve their competence and confidence in teaching a subject in which they have previously had limited background. Further research is needed that problematises the assumption that disciplinary training automatically and alone leads to effective teaching. Such research could explore those experiences that teachers teaching out-of-field believe are instrumental in developing confidence and competence in their teaching.

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