“No wonder out-of-field teachers struggle!”

Unpacking the thinking of expert teachers

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According to McKenzie, Weldon, Rowley, Murphy and McMillan (2014, p. 67), in 2013, approximately 27% of Australian Year 7—10 mathematics teachers had received no teaching methodology education in mathematics and hence could be considered to be teaching out-of-field. The corresponding figure for science teachers was 20%. Furthermore, the likelihood of students being taught mathematics by an out-of-field teacher is greater in provincial or remote schools compared with metropolitan schools (Office of the Chief Scientist, 2012). Teachers in such rural or remote locations also tend to be less experienced and have limited access to professional learning and the support of expert colleagues compared with their metropolitan colleagues (Lyons, Cooksey, Panizzon, Parnell, & Pegg, 2006). Yet when an expert teacher is available, the task of mentoring out-of-field and less experienced colleagues is often undertaken with little acknowledgement or support. In this paper, we describe the initial stage of developing a framework designed to support out-of-field, less experienced or isolated mathematics and science teachers to make decisions about the use of resources in their teaching. The process highlighted the complexity and extent of the knowledge on which expert teachers draw in making such decisions and thus underscored the enormity of the task of teaching out-of-field. The eventual product, the Science, Technology, Engineering and Mathematics: Critical Appraisal for Teachers (STEMCrAfT) framework has proven useful not only for the target audience, but also as a tool for colleagues who take on a mentoring role. We begin with a brief description of teacher knowledge before describing the project and then presenting what we unearthed about expert teachers’ thinking and knowledge.

Teacher knowledge

While there is agreement that teachers draw upon a broad knowledge base in the course of their work, a major challenge in attempting to scaffold the thinking of out-of-field and less experienced teachers arises from the fact that much expert teacher knowledge is tacit. Shulman (1987, p. 8) described the knowledge of teachers as elaborate and proposed that teachers need at least seven different kinds of knowledge. These were: content knowledge; general pedagogical knowledge; curriculum knowledge; pedagogical content knowledge; knowledge of learners; knowledge of educational contexts; and knowledge of educational ends, purposes and values. Shulman’s ideas have been taken up by both mathematics and science educators and elaborated in a variety of ways (for example, Ball, Thames & Phelps [2008] for mathematics; Magnusson, Krajcik, & Borko [1999] for science). Pedagogical content knowledge has been of particular interest, with efforts made to understand the ways in which content and pedagogical knowledge combine and interact to produce it, how it relates to other knowledge types, and how it is developed. It is dependent upon both content knowledge and general pedagogical knowledge but is more than simply the sum of these—it takes much more than learning mathematics content (as difficult as that is) to turn a generalist teacher into an effective mathematics teacher. Pedagogical content knowledge allows an expert mathematics teacher to, for example, offer explanations and examples, and representations of mathematical ideas that make mathematics understandable to students.

The STEM: Critical Appraisal for Teachers (STEMCrAfT) project

The STEM: Critical Appraisal for Teachers (STEMCrAfT) project aimed to assist mathematics and science teachers, and particularly those in rural and remote areas, to navigate the plethora of resources available for teaching mathematics and science. It did so by developing a framework that helps scaffold these teachers' thinking and could also be used by more expert teachers to mentor less experienced or less well-qualified colleagues. The framework along with further details of the project and associated resources can be accessed from the project website: http://www.utas.edu.au/education/research/research-groups/maths-education/stemcraft-project.

Development of the STEMCrAfT framework

The STEMCrAfT framework was developed collaboratively by both expert and less experienced teachers of mathematics and science, for whom we hoped the finished product would be useful, and teacher educators. As a starting point we worked intensively over two days with a group of 15 very experienced and well-qualified teachers of mathematics and science to make visible their thinking as they made decisions in relation to the use of resources in their teaching. We began by providing the teachers with a resource, and asking them to reflect upon what they actually think about when choosing and then using a resource, in each of the three stages of reflective practice before, during and after teaching (Schon, 1983). The three questions to which teachers responded are shown in Figure 1. The teachers then shared their thinking in small groups before a single list was created based on the thinking of the whole group.

1. Reflection for planning—what do you do prior to teaching a lesson/unit of work, prior to searching for and choosing a resource to support your teaching and your students' learning?
2. Reflection during practice—what do you do as you are teaching the lesson/unit and utilising the chosen resource?
3. Reflection on practice—what do you do as you reflect back on the lesson/unit of work which utilised the resource?

Figure 1. Questions to prompt reflection.

Tables 1 to 3 list the final set of responses generated in relation to each of the questions in Figure 1. We have attempted to classify them according to Shulman's knowledge types. This was not a straightforward exercise for at least three reasons. First, it was not always clear precisely what the teachers were intending from what was said or recorded. Secondly, some of the considerations they raised included two or more aspects that could have been placed in different categories but rather than splitting them up and thereby losing the context, the whole item has been placed in a single knowledge category. And finally, several of the types of knowledge are difficult to distinguish. This applies particularly to general pedagogy and pedagogical content knowledge. Since Shulman's initial description of pedagogical content it has been conceptualised in a variety of ways in relation to content knowledge (e.g., Ball et al, 2008; Chick, Pham & Baker, 2006; Magnussen et al., 1999). Common to the various conceptualisations is recognition of the close relationship between pedagogical content knowledge and content knowledge, and their mutual entailment. In spite of the difficulties of categorisation, the classification exemplifies the range of different sorts of things that teachers think about when considering teaching resources, and hence highlights the different kinds of knowledge on which they draw.

As shown in Table 1, when the teachers thought about the planning to use a resource, they drew on knowledge from all of Shulman's (1987) categories except for the knowledge of educational ends, purposes and values. Pedagogical content knowledge was the category most frequently drawn upon. Teachers drew upon fewer knowledge types when reflecting upon their thinking when using a resource (Table 2), or considering what it is they think about after using a resource (Table 3). Knowledge of general pedagogies, pedagogical content knowledge, knowledge of learners, and knowledge of educational contexts in terms of school organisation and collegial relationships were common to both. It is apparent, however, that expert teachers think about a great many things in making what might be considered a relatively mundane teaching decision—should I use this resource? Undoubtedly the lists would have been longer had the teachers been asked to consider the whole of their teaching. It is noteworthy that the teachers were inclined to use questions to express what they considered when making a decision about a resource.

Table 1. Reflection for planning.

Type of knowledge	Teacher thinking/knowledge
Content knowledge	What is the big idea, specific outcome you want?
	Links to previous topic.
	New language, vocabulary, glossary.
	Practise new activities, questions, make sure you know the stuff well.
General pedagogical knowledge	How could I familiarise the kids with the resource before using it in teaching – allowing playtime, exploration?
	Formative and summative assessment.
	Checking equipment.
	Making sure props work.
	How exactly will I use this material—is there enough for each child, pairs, groups ...?
	How can I keep track of the pieces?
	What dangers might there be? For example, small parts, things to throw. ...?
Curriculum knowledge	Curriculum, Tasmanian Qualifications Authority, what do I have to teach?
Pedagogical content knowledge	Connections of this topic with daily life.
	How might I bridge any gaps that emerge, contingency plans?
	Links to skills in other curriculum areas, school events.
	What differentiation points are there?
	How can I use misconceptions?
	How can I make content relevant and accessible to students?
	Hook to capture interest, intro activity, maybe connecting to last topic.
	How could I use a multitude of resources together?
	What conceptual jumps are involved in moving between resources, representations?
	Which resource would I start with?
Knowledge of learners	What do students bring to the topic—could they access this resource?
	Is there something about the resource that might confuse kids?
	Where to I anticipate kids will struggle? How can I pre-empt?
	How can I say enough but not overload (KISS principle)?
Knowledge of educational contexts	Do I have a colleague who has taught this before?
	Is it available for my lesson—do I need to book?

The expert teachers expressed surprise at the length of the lists they created and the complexity of the thinking that these represented. As expert teachers they typically considered and answered many of the questions listed with little conscious effort. It was clear to them that for the less experienced or out-of-field teacher most of the questions and issues would take time to think through and answer. While it is generally acknowledged that such teachers would need to master the content, these lists highlight their need to research and learn much more than content alone. This of course assumes that a less experienced or out-of-field teacher is aware of the things that need to be considered and the questions that need to be asked and answered. A major part of the value of the STEMCrAfT framework is in making expert teachers' knowledge and thinking explicit and helping less expert teachers to think systematically through the issues that should underpin their decisions about the use of a particular resource in their specific context and with their students.

Table 2. Reflection during practice.

Type of knowledge	Teacher thinking/knowledge
General pedagogical knowledge	Are they engaged?
	How can I cope with an unexpected interruption or change?
	Making mental notes.
Pedagogical content knowledge	Questioning – is this achieving the desired outcomes, are kids learning what I wanted them to?
	Do I need to change tack?
	How can I do this better?
	How can I capitalise on a teachable moment?
	Identifying student misconceptions, understandings—confirming or adding to those anticipated.
	Should I cut my losses?
Knowledge of learners	How are the students engaging with the resource?
	How can I use something unexpected that kids bring?
Knowledge of educational contexts	Am I keeping the time schedule?

Table 3. Reflection on practice.

Type of knowledge	Teacher thinking/knowledge
General pedagogical knowledge	How could I manage the time-line better?
	Documenting mental notes—what worked well?
	How can I check that students understand the resource —for example, make their own?
Curriculum knowledge	Did I meet the curriculum expectations, teach what I needed to?
Pedagogical content knowledge	Would I use it again—why/why not?
	How can do it better/smarter?
	Why didn't it work?
	Keep, improve, discard?
Knowledge of learners	Did it work for all or most students?
Knowledge of educational contexts	Time for collegial discussion? Sharing ideas.
	Rate my resource.com.au

Subsequent development and use of the STEMCrAfT framework

Following the initial work described here, a draft STEMCrAfT framework was created. True to the ideal of modelling the tacit thinking of expert teachers, the framework is made up of a series of questions, as this is the way that our teacher participants expressed themselves as they documented their thinking. Subsequently, drafts of the STEMCrAfT framework were tested with out-of-field, less experienced and isolated teachers in Tasmania and Western Australia.

The final STEMCrAfT framework has been used in several different ways and for several different purposes. Less experienced and out-of-field teachers working in rural and remote contexts, and in isolation from expert colleagues, have found it useful for guiding their thinking. Mathematics and science teachers have also reported finding it useful when working in teams to plan their year's teaching. Finally, expert teachers have used the framework when mentoring out-of-field colleagues and teacher education students on placement. They have found that the framework can prompt conversations about the complexity of teaching mathematics or science and provide a structure for ongoing individually tailored professional learning.

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