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EXPLICATING THE ELUSIVE ‘PEDAGOGICAL REASONING’ OF EXPERT TEACHERS OF SCIENCE

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ABSTRACT: Quality teaching that enhances student learning and engagement in science is a focus for all educational systems. Whether fuelled by the results from international studies, such as the Programme for International Student Assessment (PISA), or from what is already evident from the research, highly skilled teachers can greatly improve the educational outcomes of students (MOURSHED, CHIJIOKE & BARBER, 2010). It is this fundamental principle that underpins the recent development and implementation of the Australian Professional Standards for Teachers (APSTs), which identify explicitly the qualities that teachers are expected to demonstrate in each of four career stages: Graduate, Proficient, Highly Accomplished, and Lead (AUSTRALIAN INSTITUTE FOR TEACHING AND SCHOOL LEADERSHIP [AITSL], 2012). Underpinning teacher quality in at least four of these standards is the elusive tacit or pedagogical knowledge that is held and used by ‘expert’ teachers of science in their teaching. The study discussed in this paper set out to explicate the knowledge or ‘pedagogical reasoning’ brought to a teaching context by expert teachers *as they plan to teach science*. The three-year longitudinal study incorporated two cohorts of teachers representing elementary and high school teachers of science ($N = 40$) in one state in Australia. Data were collected from audio recordings of pairs of teachers as they designed units of work, interviews with pairs of teachers, and other ad hoc data collected during workshops conducted with the teachers throughout the study. Analyses of these data revealed non-linear, complex, and rapid interactions between five distinct, but richly connected focal concepts that comprise teachers’ pedagogical reasoning. The five focal concepts were termed: Big Ideas; Student Engagement; Quality Learners and Quality Learning; Contextual Constraints and Opportunities; and, Teacher Personal and Professional Identity. The study illustrates the rich web of professional wisdom and pedagogical reasoning that underpins the classroom practices of expert teachers of science and why this knowledge is crucial to understand if we are to nurture our next generation of teachers of science.

KEYWORDS: Pedagogical reasoning; Teachers’ professional knowledge; Tacit knowledge.

INTRODUCTION

In many countries teaching standards are being used as of means of enhancing teacher quality (AITSL, 2012; DEPARTMENT OF EDUCATION, 2011; NATIONAL BOARD FOR PROFESSIONAL TEACHING STANDARDS, 2014). Critically though, the standards express what teachers are expected to be able to do although they often provide little detail about the teacher reasoning and expertise required to demonstrate these standards. *What is required for teachers to apply these standards in their own teaching of science*? Pushing this even further: *What do expert teachers of science do that demonstrates their alignment to these standards*?

Focusing on teacher quality and teacher knowledge is not new. In his American Educational Research Association 1985 Presidential Address, Shulman suggested that teachers' professional knowledge was undervalued and not well articulated – a claim that continues to resonate today. He criticised teacher effectiveness research and the sterile, reductionist ways this was incorporated into policy usually leading to simplistic and rigid checklist requirements as part of teacher education. In response to the situation, Shulman (1987) offered a way of conceptualizing the tacit knowledge of teaching by drawing attention to *pedagogical reasoning* - the thinking and planning that a teacher does in designing and preparing lessons *prior* to teaching. It is planning that is crucial to innovation in teaching and ensuring that learning outcomes are aligned to the needs of the students (HASHWEH, 2005; MERCIER, 2012). Shulman argued that the knowledge of the expert teacher was equal to the expert knowledge of other professionals and should not be taken lightly. At the time, he was disappointed by the ways in which teaching and teachers were portrayed and so attempted to challenge the simplistic portrayal of teacher knowledge by employing pedagogical reasoning as a window into the expertise of their practice.

The study represented in this paper builds on the work of Shulman (1987) because in our view, pedagogical reasoning highlights the difference between the simple search for, and application of, "*activities that work in the science classroom*" (APPLETON, 2002) with a focus on the expertise that underpins the quality practices evident with expert teachers of science. It deliberately incorporates both elementary and high school expert teachers of science. Given that elementary teachers do not usually have specialized degrees in science as their high school peers, the notion of them being 'experts' might be challenged. However, we defined expert for this study around pedagogical practice. Expert teachers consider not just what to teach and how to teach within a science topic, but the reasoning behind their teaching in relation to the kinds of student learning and engagement that underpins their educational beliefs and values (LOUGHRAN, 2002). As such, this definition is relevant to all teachers although we recognise that care must be taken in selecting 'expert' teachers. By making the pedagogical reasoning of expert teachers clear (regardless of the year level taught), teaching as a profession can be conceptualized as more than technical rationality (SCHÖN, 1983). It offers new ways of unpacking how teachers with high levels of pedagogical expertise develop and use their professional knowledge of practice to shape students' learning.

In this paper, the research around pedagogical reasoning is summarized, followed by a description of the Australian educational context in which the three-year study was undertaken. The research design is then presented around the professional learning workshops that allowed the research team to work with teachers throughout the project. Finally, results are discussed in relation to each of the five key focal concepts that emerged from the study.

CONCEPTUAL FOUNDATIONS OF PEDAGOGICAL REASONING

In a seminal article on rethinking the knowledge base of teacher education, Shulman (1987, p. 15) defined pedagogical reasoning as the process of [teachers] "*transforming subject matter knowledge into forms that are pedagogically* *powerful”*. It refers specifically to the thinking and planning undertaken by teachers as they design and teach their lessons placing the emphasis clearly on the “*intellectual basis for teaching*” rather than just on the behavioural outcomes (p. 20). The term was first used by Shulman to conceptualise the sophisticated and tacit knowledge about teaching that expert teachers carry ‘in their heads’. Polanyi and Sen (1967) considered the tacit nature of this practice as the hidden basis for intelligent action while Spender (1996) defined knowledge as ‘*that which has not yet been abstracted from practice*’ (p. 67). Sternberg and Wagner (1994) argued that tacit knowledge is important in identifying expertise, and Eraut (2000) considered that tacit knowledge was difficult to elucidate as there are always multiple representations of knowledge embedded in complex situations, such as teaching. Hence, trying to explicate this tacit knowledge of teachers has been pivotal to teacher education research for decades.

Shulman’s work (1987) deliberately set out to counteract the teacher effectiveness research at the time, which presented teaching as a sterile and reductionist activity overlooking the deeply complex and sophisticated knowledge that expert teachers bring to their interactions with students. Exploring the area further, Shulman found that teachers worked through six stages when planning to teach.

- *Comprehension*: Teachers develop an understanding of the set of ideas to be taught along with how one idea relates to other ideas in the subject area but also with other subject areas.
- *Transformation*: Teachers’ understandings of the subject matter are transformed into ways of knowing for the learners. This process requires moving from the personal comprehension of the teacher to focus on the comprehension of others with planning and thinking associated around the best ways of supporting students’ learning.
- *Instruction*: Enactment of the teaching and pedagogies including questioning, checking student work and ideas, organization of the learning environment while also building relationships with students.

- *Evaluation*: Checking for understanding of the learner that requires teachers to understand not only the material and skills but also the processes of learning.
- *Reflection:* Teachers look back over their teaching to consider what has been learned, whether the experiences were supportive of student learning, and the student emotions positive.
- New comprehensions: The teaching experience provides new insights and comprehensions that further impact the next teaching experience resulting in a new beginning.

In his view, Shulman considered this sequence to be cyclical, beginning and ending with comprehension. Initially, this appears quite reasonable with some evidence for it at the time. However, it represents an essentially linear process with one stage following the other. Shulman's work stimulated considerable research but few studies unraveled the pedagogical reasoning that drives and underpins very sophisticated teaching practice. We argue that pedagogical reasoning is captured by Shulman's comprehension, transformation and instruction stages defined above. In contrast, considerable research in teacher education over the last two decades has focused on 'reflective practice', which aligns with the evaluation, reflection and new comprehensions stages defined above.

Another key observation from the many studies exploring Shulman's work is that 'experience' is regarded as equivalent to 'expert'. While more years of teaching provides a larger number of past episodes to reason over and may be one type of expertise, making judgements about the skill of a teacher is more aptly referenced to broader criteria. Expert teachers do things that makes their practice stand out using pedagogical reasoning that actively shapes what they do, how they do it while providing the justification for their teaching. Expert teachers consistently:

(i) Challenge their students to engage in high order thinking;

(ii) Focus on deep rather than surface cognitive processing that builds rich understandings;
(iii) Particulate a range of aspects of quality learning; and
(iv) Describe and plan teaching to promote specific cognitive strategies that are relevant to the lesson at hand while being sensitive to and quick to reinforce a range of effective learning behaviours (KEAST, MITCHELL, PANIZZON, LOUGHRAN, & THAM, 2015; WHITE & MITCHELL, 1994).

Claxton (2007) referred to such expertise as 'split screen thinking' whereby expert teachers have both a content agenda (i.e., the curriculum requirements) and a learning agenda (i.e., building the learning abilities of students). Expert teachers problematize their practice; express dissatisfaction with passive, dependent, unreflective learning; and, are innovative in devising ways of tackling these problems in the classroom. As such, they allow their students to take greater control of their learning with the teachers creating a sense of shared intellectual control in the classrooms.

RESEARCH METHODS

Context

A number of the key ideas that underpin the present study emerged from an earlier pilot project conducted by researchers Mitchell and Mitchell (2011) with a group of 10 committed elementary and high school teachers. The focus of the group (termed pedagogical purposes group [PPG]) was on pedagogy and not confined to a particular discipline area. Over a period of five years, the PPG met at regular periods to share their common interests in unpacking their pedagogical practice and the reasoning behind what and why they taught in a particular way. A critical part of these discussions were the observed impacts on students' learning over time. Data were collected over the five years. Analyses demonstrated the emergence of a shared language and learning agenda within the PPG along with four consistent focal concepts in their pedagogical reasoning. These concepts were termed:

- Big ideas;
- Student engagement;
- Quality learners and quality learning; and,
- Contextual constraints and opportunities.

Research questions

The present study set out to explore pedagogical reasoning with a larger group of teachers within science to test the applicability and the validity of the four focal concepts identified from the PPG with an extensive group of teachers.

The main question guiding the study was:

> Can pedagogical reasoning be used in the teaching of science to better understand teachers' professional or tacit knowledge while offering richer ways of interpreting and using teaching standards to judge their expertise in practice?

The following subsidiary questions were used to unpack the main question:

1. How can pedagogical reasoning be delineated in ways that the elements of high quality pedagogical reasoning can be recognized when observed?
2. What forms of representations of PR do teachers of science find intelligible, plausible, fruitful and feasible and why?
3. How does making PR explicit impact the practice of teachers of science over the longer term?

In this paper, Qs 1 and 2 are addressed in relation to the main research question.

Participants

The three-year project comprised 40 teachers. All teachers were identified as 'expert' not because of their years of teaching (the criterion reported in some studies) but based upon two criteria: (i) involvement with the researchers (authors) in professional learning science projects over a number of years; and (ii) recognition by their employers as being highly motivated and interested teachers of science who lead science projects within their schools. As part of selection, all teachers submitted an expression of interest to participate in the study. In this manner, the sample was purposively selected to ensure a high calibre group of teachers committed to high quality teaching in science.

Design of the study

Teacher participants formed two cohorts with 20 elementary and high school teachers in each (see Table 1). Cohort 1 commenced in 2014 and Cohort 2 in 2015. Each cohort of participants was involved in a professional learning program involving pedagogical reasoning over a period of five full-day meetings in the first year of the project followed by three days in the second year. Cohort 1 also had additional days allocated to writing up their experiences in the third year, which was organised on an individual basis with teachers. The purpose of Year 1 was to explore the nature of pedagogical reasoning giving teachers the opportunity to listen to other teachers as they planned to teach a new unit of work while interrogating their practice. This involved asking a series of questions, such as: *Why are we teaching this? What science? What skills? Why is this relevant to the students? What do we want the students to learn? How are we developing their learning skills? Why will this work?* As teachers listened to various taped conversations (including their own), they tried to identify common themes or foci that emerged from these planning discussions.

The aim of Year 2 was to take what pairs or teams of teachers had learned in the first year and apply it in some leadership capacity within their own teaching contexts. The way in which this was embedded within each school was highly contextualized given the nature of the schools. Teachers were supported in doing this by the authors.

Table 1. Overview of research designs for cohorts 1 and 2

2014	2015	2016
Cohort 1 – Year 1 • Introduction to pedagogical reasoning– 5 days of workshops over year. • Teachers audio capture their planning discussions in an ongoing manner. • Additional data collected throughout the year.	**Cohort 1 – Year 2** • 3 days of workshops over year with leadership focus. • Teachers audio capture their attempts to lead pedagogical reasoning within school. • Additional data collected throughout the year.	**Cohort 1 – Year 3** • Writing school-based cases around pedagogical reasoning. • Funding provided.
	Cohort 2 – Year 1 • Introduction to pedagogical reasoning– 5 days of workshops over year. • Teachers audio capture their planning discussions in ongoing manner. • Additional data collected throughout the year.	**Cohort 2 – Year 2** • 3 days of workshops over year with leadership focus. • Teachers audio capture their attempts to lead pedagogical reasoning within school. • Additional data collected throughout the year.

Data collection and analyses

Data were collected using four key methods throughout the project. Firstly, each teacher involved in the project was given a digital voice recorder to capture conversations while planning lessons with peers and when designing and preparing a teaching event. Files were uploaded to allocated folders on an external server with restricted access for individual teachers only and the researchers. Files were transcribed and coded using content analysis initially. Secondly, interviews were conducted with teachers in each school between professional development days to explore more deeply any growth or change evident in their pedagogical reasoning. Thirdly, data were collected during the professional development days as teachers interacted with various activities and were required to report back to the group. Finally, time was given near the end of the projects for teachers to write vignettes from their own experiences.

In terms of analyses, different sources of data were mapped against each of the research questions so that triangulation occurred. The frequency of particular themes or comments identified through content analysis was recorded to distinguish core concepts that were universal across the participants from rare and inconsistent concepts (HARRY, STURGES, & KLINGNER, 2005). All data points were eventually mapped onto matrices so that patterns could be studied more carefully.

RESULTS AND DISCUSSION

The analyses of data supported the four key foci that were identified in the work of the pedagogical purposes group (PPG). Importantly though, there was further refinement of these focal concepts that involved greater delineation of the pedagogical reasoning comprising each concept. The emergent focal concepts for the present study were termed:

- Big ideas;
- Routes to student engagement;
- Generation of quality learning and quality learners and,
- Responding to contextual constraints and opportunities.

However, a further focal concept emerged from the data labelled '*Teacher personal and professional identity*'. Each of these five focal concepts is elaborated and discussed in this section.

Big ideas

A big idea is a unifying principle that connects and organizes a number of smaller ideas or concepts and multiple experiences (MITCHELL, KEAST, PANIZZON, & MITCHELL, 2017). Importantly, big ideas are not merely topics or traditional textbook headings but are unifying statements. This point is exemplified in the following excerpt from Mary, a high school science teacher:

> When planning to teach respiration and photosynthesis, I started by providing the larger scientific framework: how **building complex molecules requires energy while breaking up complex ones releases energy**, and how energy is needed for vital cellular processes.

The big idea in bold provides a way for the Mary to explain some difficult scientific content while also helping to link several different bio-chemical processes. This is a clear example of how teachers in the study demonstrated their ability to construct a big idea to guide their practice that was generative in that it offered links to other scientific ideas. Integration is one role that makes big ideas pedagogically powerful because they offer direction for teachers to make student learning more connected (MITCHELL ET AL., 2017). The big idea is used by the teacher *to plan their teaching* and is not meant as a goal for students although many of us would be delighted if our students were able to conceptualize their scientific understandings in this way.

Further results from teachers identified five purposes for big ideas when teaching science.

1. Introducing and organizing specific content

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2. Providing a basis for students to restructure their existing ideas
3. Introducing an idea about the domain, not the content (i.e., big ideas about the scientific method refer to the domain because they do not relate to a specific content area)
4. Connecting the topic being taught to students' experiences, and thereby
5. Providing relevance for students.

It was interesting that Big ideas as a focal concept also generated the most discussion and argument among teachers. There appeared to be a clear distinction between the way in which elementary and high school teachers thought about and implemented big ideas in their teaching. Elementary teachers often use the term big idea as a *unifying topic* to build coherence across a number of subject areas rather than as a statement of connectedness as demonstrated in the example above. This is a likely consequence of elementary teachers in Australia being expected to teach all discipline areas although they may not hold any particular discipline specialization. This contrasts to high school teachers of science who should hold a university qualification in order to teach science at this level.

Routes to student engagement

'Routes' into engagement refers specifically to the tasks or strategies used by teachers to encourage student participation in learning and it is this aspect that prevails in the literature. Engagement however, is a complex meta-construct (FREDRICKS, BLUMENFELD, & PARIS, 2004) categorised into behavioural, psychological (or affective), and cognitive dimensions. More recent additions include *meta-cognitive* as students focus on their own learning (MITCHELL, CARBONE, 2011) and, *agentic* whereby students are encouraged to contribute to the flow of teaching (REEVE & TSENG, 2011).

The data were rich in terms of the number of coded comments from teachers aligned to the student engagement focal concept. It was noted that the teachers seemed to be very sensitive to, and confident about what was either likely or unlikely to engage their students in science. Hence, we identified no deficit discourse in the way teachers discussed engagement, nor was there a strong focus on behavioural engagement except when they considered factors, such as students getting tired.

The teacher discourse for this concept was around (and coded for) affective, cognitive and more rarely, metacognitive engagement that was driven by the teachers' intentions to promote different aspects of quality learning. However, we stress that many routes to engagement have elements of more than one of these dimensions. For example, for many students a route to engagement was via group work and collaborative tasks. But this also had affective elements (many students like working in groups) and metacognitive elements as teachers included 'reflection of' and 'discussion about' effective group behaviours (MITCHELL ET AL., 2017).

There were many comments that were coded as routes to affective engagement because of recognition of *perceived relevance*. Examples included the use of local artefacts (e.g., wind farm), connecting to societal experiences (sometimes in ways that deliberately challenged students' values), or connecting to personal experiences including ones that had an emotional dimension. Other teachers used popular media to frame intriguing questions. For example, the government road safety authority in Australia funds dramatic television advertisements about road safety. This resource stimulated a pair of teachers to ask: *What is the science used to make a car safe*? The planned outcome was an investigation to be undertaken by students around how air bags (as one example) slow the rate of deceleration during a crash and (by Newton's second law) reduce the force on car occupants as they decelerate.

The strongest theme in the data (with the highest number of references) was for cognitive engagement as the teachers used thinking about quality learning and deep processing as a route to mentally engage their students. The majority of teachers considered that this would in most instances normally eliminate problems with behavioural engagement. A number of strategies were evident in the data.

1. Scaffolding ways that students could discover or work out part of the scientific content for themselves.
2. Conducting practical investigations by allowing students to answer a genuine question i.e., not just demonstrating or 'proving' some known piece of science.
3. Promoting cognitive engagement by building a sense of shared intellectual control (MITCHELL, 2010). One way of doing this was to give students different sorts of choices and opportunities for decision-making.
4. Sharing intellectual control by using student-generated questions. Many elementary teachers gave their students some shared experiences in a new topic and then set up a 'wonder wall' of student questions that drove the teaching. For example, a wonder wall question on the water cycle (from a class that had studied gravity) was: *Why does steam go up?* This raised several issues in the discussion that positioned students as intellectual partners in the classroom discourse.

Generating quality learning and quality learners

The authors make the distinction between *teaching for quality learning* and *teaching for quality learners*. Teaching for quality learning occurs when teachers are focused on building strong learning episodes for learners by building on prior learning, creating connections to other contexts and giving real world examples. It is where teachers meet the curriculum requirements. Expert teachers do this but often have another agenda to build quality learners. To do this the teacher may introduce a 'teaching procedure' (MITCHELL & MITCHELL, 2013) that builds quality learning, while being discussed explicitly with students so that they can use it in the future. Having two simultaneous agendas for teaching has been labelled 'split screen' thinking (CLAXTON, 2007), where teachers observe their teaching through the lens of building quality learning and another lens whereby they create quality learners. Teachers with a focus on quality learning often include in their planning when they will introduce each learning strategy, when they will reintroduce it, and when they offer a task that could be used without introduction. In this way they have a teaching for learning agenda that operates in parallel with their curriculum learning agenda.

The following excerpt provides an example of this ‘split-screen thinking’. A group of five teachers discussed an elementary science unit on water to be taught. After the initial introduction of the Big idea, ‘*Water is Life’*, Angela begins with a discussion of the possible learning skills for the unit.

> A: I agree. I guess it’s just something that everything hangs off [the Big Idea]. So all your content is linked back in to this main overarching idea. And then sitting behind that or supporting it are the actual skills. And they run vertically across all the content to support it in each of the domains.

A short time later, Tim contributes.

> T: In theory, what we wanted to be doing in these two weeks is looking at skills. How to identify questions. How to recognise metacognition. How to recognise what students are really thinking about. Questioning the validity of information. So we've talked about all these little explicit skills that they are not going to just stumble across and have a realisation. Maybe if they had a lot of time they would. But we provide them with these skills, and we do it through the scope of the particular piece of content that is consistent across all of us, but they have the scope to identify some big ideas that are of interest to them.

Here the teachers as a group construct the agenda for building quality learners.

Responding to contextual constraints and opportunities

There are many constraints that need to be considered in relation to planning to teach (i.e., tiredness and prior experiences of students; teaching spaces available). Expert teachers know their students and tend to capitalize on aspects that support their learning. As part of planning to teach, expert teachers in this study identified potential constraints upfront then found ways to deal with these often turning them into opportunities for learning. Hence, they were not hindered by constraints.

Teachers were sensitive to the capabilities, likely motivators, and sources of engagement for their students. They demonstrated that they were *reactive* as they planned teaching appropriate to the learning behaviours of their students while also being *proactive* as they capitalized on opportunities to improve aspects of students' approaches their learning. In planning their teaching, the teachers considered the nature of their students, the time of day they were teaching, and the physical resources available, all of which then impacted their teachers' pedagogical reasoning. Rather than respond to difficult constraints by setting mindless busy work that avoided management problems, data from our expert teachers indicated that they did not compromise their educational values but rather capitalized on opportunities and managed possible constraints (PANIZZON, BARNES, & PEGG, 2007).

In this example two expert teachers in a female-only high school discuss their next unit of work around 'Motion'. As they work through their planning they consider the constraints and opportunities of teaching this unit based upon their experiences in previous years.

> Brenda: So we've decided to look at our next unit for Year 10 science and that is motion
>
> Corine: I think the hardest thing with the physics concepts is making them more concrete. Given you've said things like

> they had difficultly interpreting graphs and what it means in relation to physical motion - that's an important thing to consider. These kids are very visual learners and so how are we going to get them to understand it?

Here Corine and Brenda acknowledge the possible difficulties their students might have with learning the topic (i.e., constraints). They look for opportunities, in this case the need to make concepts more concrete while linking them to the everyday lives of the female students they teach. As such, these teachers illustrate their expertise in identifying a constraint and turning it into an opportunity for student learning.

> Corine: The thinking needs to be on multiple levels so that they can see applications to the real world. We need to incorporate it so it would be good if we could get filming with ipads, it would be good to get some safety into here to bring in like [TV] ads
>
> Brenda: Because they're at that age when they are getting their initial driver's license they are interested in roads and cars and safety and I think that we could turn it from a fairly esoteric physics unit bringing points of connection for them all over the place
>
> Corine: Maybe that could be an underlying theme –they're all going to be road users shortly they're going to be driving cars so also providing a rationale that they would see as palatable to make it more sellable. At least it will win them on side for those female students who think that this is only a boy's thing!

Teacher personal and professional identity

Emerging from this project is the importance of a teacher's identity in shaping their pedagogical reasoning. We conceive of professional identity as the way in which teachers understand themselves and their role within the teaching profession that is underpinned by their own personal identity, which includes core values. Findings demonstrated that both identity and values influenced the decisions made by teachers in planning lessons and the ways in which they conceptualized the other four focal concepts of Big ideas, Quality learning and quality learners, Student engagement, and Responding to constraints and opportunities.

The following excerpts explicate what is meant by the identity focal concept using examples from Steve and Bill (elementary teachers) and Helen (high school teacher). Initially, the teachers begin by considering Big ideas, which immediately leads onto a discussion about the differences between the elementary and high school teaching contexts for science. Importantly, embed in this discussion are teacher values regarding the way in which science is and should be taught.

> Steve: How to implement Big ideas and the reasoning behind it is tricky.
>
> Bill: Although there are different school types big ideas provide similar ways of getting other teachers to think about their reasoning particularly with science.
>
> Helen: The high school perspective is so content driven!
>
> Bill: We focus on making it interesting so they will continue with science in the high school.
>
> Helen:You probably do a really good job of that and then we lose them. It becomes really content and theory driven rather than practically based. Nearly every Year 7 student comes into high school engaged and super excited to be there and by half

way through Year 8 they have had it because we are too content focused!

Steve: In elementary school, science can be fitted in through any subject. We are time rich that is where the difference is.

Bill: For me it's about getting teachers on board and science being everywhere. Some teachers feel that only experiments are doing science and that it can only be taught using certain terms or language.

Bill: Are they intimidated? It's more a perception. Is it a lack of scientific knowledge? You teach to your strengths. We need to build up the confidence of these elementary teachers and show them that science is in everything, like the Olympics.

Helen: High school teachers are all strong with a science discipline knowledge and so they are very engaged, but they need to be able to embed content in skills and literacy in terms of reading and writing and scientific literacy.

In this conversation, the teachers discuss the different perspectives they bring to their teaching based upon the sector in which they work. As demonstrated here, science takes on a different perspective. In high school it is very content-driven within the silos of biology, chemistry, Earth science and physics. However, in elementary schools science often emerges from the interests of the students. It is up to the elementary teacher though to generate the interest. Each teacher working in the different sectors views science from their own perspective relative to their teaching and students. Professional and personal identities are intrinsically linked to personal values, which ultimately impact the ways in which each teacher thinks about science and how it is best implemented to nurture and build student learning and competent learners of science.

TYING THE FINDINGS TOGETHER

The foci of this paper were:

> *RQ1: How can pedagogical reasoning be delineated in ways that the elements of high quality pedagogical reasoning can be recognized when observed?*
>
> RQ2: *What forms of representations of pedagogical reasoning do teachers of science find intelligible, plausible, fruitful and feasible and why?*

Findings demonstrate that the five focal concepts discussed above captured the pedagogical reasoning of the expert teachers participating in this study (RQ1). When a summary of these findings was shared with both cohorts of teachers, they agreed that the five focal concepts were intelligible, plausible, fruitful and feasible (RQ2). Supporting the teachers' validation of these focal concepts was their preparedness and ability to use the concepts to lead discussions around pedagogical reasoning in their own school contexts. Teachers reported that the focal concepts created a shared language with staff able to unpack and discuss their practice in a meaningful and universally understood manner. Furthermore, the emphasis on *planning thier teaching* (in contrast to reflecting practice) and explicating their pedagogical reasoning was reported by teachers as "*raising the quality of teacher talk and teaching in our schools*".

An important observation made in mapping data from the planning conversations of expert teachers of science was the quick and successive movement among the five focal concepts (see Figure 1). We term the quick and frequent movement of thinking between these focal concepts as 'pinball reasoning' thereby counteracting the rather linear view of teacher preparation to teach proposed initially by Shulman in 1987.

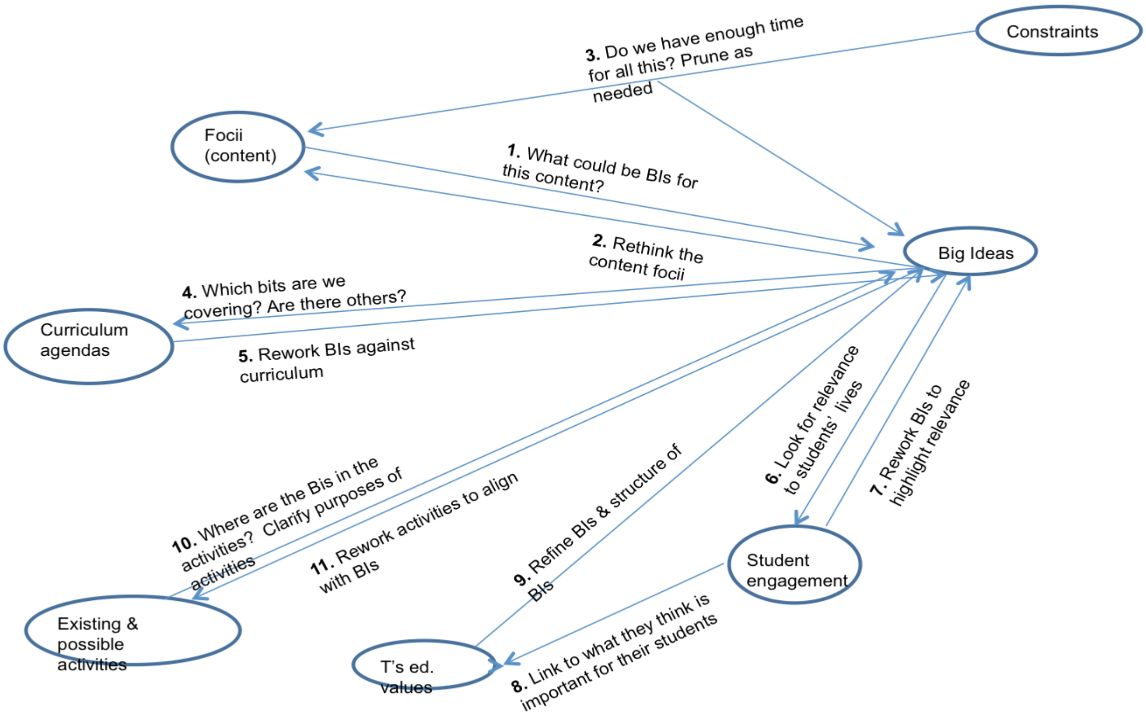

Figure 1. Pinball reasoning in teacher planning (MITCHELL ET AL, 2017, p. 282)

As demonstrated in this figure, there was a complex interplay between the focal concepts as teachers planned a teaching sequence. For example, a constraint and/or opportunity identified by teachers might be around the science content – e.g., volcanoes are exciting and offer easy ways into student engagement. Alternatively, some content (e.g., the periodic table) is abstract and can be boring, which resulted in discussions about how to make it more engaging. In the case of the periodic table, two teachers in the study decided to personalise Mendeleev, both the problems he faced and his scandalous private life. The key point being made here is that while the individual focus was identified, in designing and planning for student learning, teachers quickly and consistently moved backwards and forwards between the five focal concepts explored in this paper. This mapping of teacher thinking demonstrates quite clearly the complex nature of teaching in its planning phases.

CONCLUSION

By explicating pedagogical reasoning, science teaching as a profession is clearly more than technical rationality based solely on the knowledge associated with scientific content. The results from this study offer different ways of understanding how expert teachers think about, develop, and implement their professional knowledge so as to shape the learning of their students. The five focal concepts explored in this study moved beyond the surface practices of what teachers of science do, to understanding how and why they use these practices. In unpacking pedagogical reasoning using the focal concepts of Big ideas, Student engagement, Quality learners and quality learning, Responding to contextual constraints and opportunities, and Professional and personal identities we demonstrate how complex and interconnected the tacit knowledge held by expert teachers of science is. These findings reinforce the importance of planning our teaching if we are to develop competent and confident learners of science regardless of their year level of schooling.

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