

2015

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Recommended Citation

Hudson, P., English, L., Dawes, L., King, D., & Baker, S. (2015). Exploring Links between Pedagogical Knowledge Practices and Student Outcomes in STEM Education for Primary Schools. *Australian Journal of Teacher Education*, 40(6). Retrieved from <http://ro.ecu.edu.au/ajte/vol40/iss6/8>

This Journal Article is posted at Research Online.
<http://ro.ecu.edu.au/ajte/vol40/iss6/8>

Exploring Links between Pedagogical Knowledge Practices and Student Outcomes in STEM Education for Primary Schools

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Abstract: Science, technology, engineering, and mathematics (STEM) education is an emerging initiative in Australia, particularly in primary schools. This qualitative research aimed to understand Year 4 students' involvement in an integrated STEM education unit that focused on science concepts (e.g., states of matter, testing properties of materials) and mathematics concepts (e.g., 3D shapes and metric measurements) for designing, making and testing a strong and safe medical kit to insulate medicines (ice cubes) at desirable temperatures. Data collection tools included student work samples, photographs, written responses from students and the teacher, and researcher notes. In a post-hoc analysis, a pedagogical knowledge practice framework (i.e., planning, timetabling, preparation, teaching strategies, content knowledge, problem solving, classroom management, questioning, implementation, assessment, and viewpoints) was used to explain links to student outcomes in STEM education. The study showed how pedagogical knowledge practices may be linked to student outcomes (knowledge, understanding, skill development, and values and attitudes) for a STEM education activity.

Introduction

The urgency to advance science, technology, engineering, and mathematics (STEM) education is evident in the repeated calls by Australia's Chief Scientist (e.g., 2014). While science tends to dominate many of the STEM reports, engineering education is receiving less attention especially with respect to the primary school (e.g., Bullen & Haeusler, 2010). Yet, the importance of early engineering education is well documented (e.g., Brophy, Klein, Portsmouth, & Rogers, 2008; Cantrell & Ewing-Taylor, 2009). Engineering experiences can bring a real-world engagement for students towards understanding mathematical functions (Sharp, Zachary, & Luttenegger, 2006) and scientific concepts (Youl, 2001). Although some studies have investigated how STEM education may be embedded within science classes (Cantrell, Pekcan, Itani, & Velasquez-Bryant, 2006), most existing studies appear to investigate STEM within secondary schools (e.g., Donna, 2009). In addition, pedagogical knowledge for STEM education appears in need of further study to better inform the teaching of STEM disciplines.

An aim of the current unit was to explore possible linkages between pedagogical knowledge practices (Figure 1) and student outcomes in STEM education for year 4 students. For the purposes of this study, student outcomes can be considered as positive, negative or indifferent. Student outcomes have been identified around three broad parameters for

assessment, namely: (1) students' knowledge and understanding, (2) demonstration of skills, and (3) values and attitudes within the educational experience (Athanasou & Lamprianou, 2002; Brady & Kennedy, 2001).

Conceptual Framework

The general term pedagogical knowledge is used frequently when referring to the knowledge for teaching (e.g., Briscoe & Peters, 1997; Coates, Vause, Jarvis, & McKeon, 1998). Shulman (2004) suggests that gaining wisdom of practice requires trialling and evaluating pedagogical knowledge towards attaining mastery experiences (see also Bandura, 1977). Pedagogical knowledge is used to facilitate effective teaching practices in ways that aim to make learning more accessible to students. The proposed pedagogical knowledge conceptual framework (Hudson, 2013; Figure 1) provides opportunities for practices to be transferable between subject areas. It is suggested that these pedagogical knowledge practices can have applications to the teaching of STEM education.

To illustrate, pedagogical knowledge practices may include the planning of lessons and preparation of resources that target students' conceptual development in the STEM areas (e.g., Cunningham & Sherman, 2008). Apart from scheduling and timetabling lessons, planning also needs to incorporate teaching strategies (Guillaume, Yopp, & Yopp, 2007; Killen, 2013), classroom management (Burton, Weston, & Kowalski, 2009; Valencia, Martin, Place, & Grossman, 2009), problem solving by the teacher with reflection-in-action (Schön, 1983), implementation and assessment strategies (Tankersley, 2010). Appropriate content knowledge needs to be aligned with curriculum requirements and students' needs (Ball, Thames, & Phelps, 2008; Hill, Rowan, & Ball, 2005), which is also the case for STEM and engineering education. Furthermore, the teacher's questioning skills (as a learnt practice) are considered part of effective teaching. These skills can include asking convergent and divergent questions such as questions based around Anderson and Krathwohl's (2001) four dimensions (i.e., factual, conceptual, procedural, and metacognitive), lower and higher-order thinking questions (e.g., Bloom's taxonomy, 1956), and various methods of questioning (Tofade, Elsner, & Haines, 2013). Importantly, teachers who have viewpoints on pedagogical knowledge practices can incorporate personal teaching philosophies and theory-practice connections such as Bybee's 5Es (engage, explore, explain, elaborate and evaluate; see Hackling, Peers, & Prain, 2007).

There is limited research attention on pedagogical knowledge practices provided for engineering education in the primary school. In a post-hoc analysis of data, this study attempts to understand possible links between pedagogical knowledge practices (Figure 1) and student outcomes within STEM education. The pedagogical knowledge practices are interrelated statistically (Hudson, Skamp, & Brooks, 2005), and not necessarily linear, with a connection to teaching around differentiated learning. To illustrate the interconnectedness of the 11 practices in Figure 1, the following examples are possible: planning teaching strategies can assist with classroom management or preparation can include preparing for assessment for addressing students' learning needs. Within this framework a teacher can plan and timetable for a STEM activity with consideration of the preparation requirements, including resources for engaging in the activity and specific teaching strategies that may assist students to learn the content knowledge. The teacher may well be required to solve problems for engagement in the activity with pre-emptive thinking and making adjustments during the teaching and learning experience. Schön (1983, 1987) presents a key part of this process as reflection-in-action. The teacher's questioning throughout the activity is used to guide individuals and groups along with a clear implementation structure such as an informative

introduction that engages students followed by hands-on activities, which can be used as assessment and reveal student outcomes. Finally, teachers have individual viewpoints about how to enact the aforementioned practices such as how to plan, prepare, manage the classroom and assess students. These individual viewpoints vary from teacher to teacher with the notion that teachers have different views on teaching any given lesson.



Figure 1. Pedagogical knowledge practice framework

Context

This STEM education unit of work occurred at the beginning of a three-year longitudinal study titled *Developing Engineering Education in Primary* (DEEP) for grades 4-6. There were five schools involved with a total of 10 classes and 270 year 4 students. This paper reports on findings from one year 4 class comprised of 19 girls. The engineering education program was divided into two parts with approximately two and a half hours allocated for each part. Part 1 focused on developing science and mathematics concepts assigned to the engineering activity: Engineers working with materials; the problem (design, make and test a medical mission kit); exploring 3D shapes; temperature; states of matter; testing the properties of materials. Part 2 focused on the engineering activity: The problem and discussing resources; designing and making the medical mission kit; testing the covering of the medical kit design; discussions during testing; recording results; testing the strength of the medical kit design; evaluation and redesign; and feedback on the activity.

Methodology

This qualitative study gathered data through archival documents, students' work samples, photographs of student work, researcher notes, teacher documentation and interview, and student written responses to investigate pedagogical knowledge practices that may link to student outcomes in a STEM education unit of work. Archival documents included a teacher's guide and student booklet, which were devised initially by university staff with further input from teachers involved in the DEEP project. Student outcomes included: (1) work samples such as writing and drawing labelled diagrams in the student booklet, which encompassed student ideas on science and mathematics concepts, (2) designing and making a strong and safe medical mission kit to insulate an ice cube (photographs), and (3) observations of student involvement in the STEM education activities.

Teacher documentation involved the teacher writing about the pedagogical knowledge practices (Figure 1) and where student outcomes might have linked to the STEM education

unit. In a similar way, the teacher interview was linked to the pedagogical knowledge practices, for instance: (a) Planning - How did the booklet assist you with your teaching? What didn't you like about the booklet? (b) Timetabling - When did you feel students were most engaged/able to concentrate on the medical mission tasks? Why? and (c) Preparation - How did the first session (exploring 3D shapes, testing materials) help students prepare for making the medical kit? The reflective practices from teacher documentation and interview responses were post hoc, and allowed the teacher to provide information that he thought may link student outcomes to the pedagogical knowledge practices. Student written responses were included as examples of possible links to the pedagogical knowledge practices and mirrored the teacher response framework. For example, with respect to planning: How did the booklet assist you with your learning? What didn't you like about the booklet?

As an example of a pedagogical knowledge practice, one aspect of "planning" for this STEM education study involved university staff devising a student booklet that sequenced lessons with science and mathematics concepts for designing, making and testing an engineering education activity (i.e., medical mission kit). The student booklet went through several iterations and pilot testing before presenting it to school staff involved in the DEEP project for further input. Planning involved aligning national and state curriculum documents to the STEM education activities. In addition, a teacher guidebook was designed to complement the student booklet. Nine teachers from the five schools were taken through the concepts associated with the task as part of professional development prior to implementing the program. These year 4 teachers provided feedback on the student booklet and teacher's guide prior to implementation.

Data Analysis

Data were analysed according to the pedagogical knowledge practices framework (Figure 1) linked to a STEM education unit. A post hoc analysis was used to overlay the framework on the STEM activities, which ensured data were not influenced by preparing a teacher towards engaging in the framework. The teacher involved in the current study consented to this process. Data (e.g., student work samples, photographs, written responses) were also analysed with consideration of student outcomes (i.e., knowledge and understanding, demonstration of skills, and/or values and attitudes; see Athanasou & Lamprianou, 2002; Brady & Kennedy, 2001). Student written responses focused on the pedagogical knowledge practices. Teacher and researcher data were analysed for alignments with student data. It should be noted that as each pedagogical knowledge practice is interconnected, other practices would be apparent in data related to each practice. However, for the purposes of this paper, each pedagogical knowledge practice will be analysed separately to indicate how each practice may have contributed to teaching and possible influences on student outcomes in a STEM education unit.

Results and Discussion

The pedagogical knowledge practices (Figure 1) are presented in the following section with alignment to student outcomes (i.e., knowledge and understanding, demonstration of skills, and values and attitudes) for the year 4 STEM education activity, titled *Medical Mission*.

Planning

According to students' written responses, the planning within the student booklet assisted them to "understand what was going on", understand "what to do next", and "express my thoughts on the subject and let me try to express my ideas in a different format". The booklet was used as a graphic organiser (e.g., Casteleyn, Mottart, & Valcke, 2013) with inclusions such as technical terms, science and mathematics concepts, and spaces for illustrating designs and recording results to present students' knowledge, understandings and skills. Planning afforded students the opportunity to follow instructions that led to brainstorming ideas and drawing labelled diagrams, which were essential for students' medical mission kit designs. Indeed without "planning", as a way to guide students' involvement, the labelled drawings and medical kit designs may not have eventuated. Although many students opted for a rectangular prism structure for their medical kit (possibly because this shape was easier to draw), there were others who attempted other designs, such as a hexagonal design (Figure 2). According to the classroom teacher, the teacher's guide was used for "technical information" and "to create a powerpoint to structure the lesson", which was presented to the class to scaffold their understandings around the concepts and tasks. Pedagogical planning was an essential step towards students' conceptualisation of their medical mission kit design and construction.

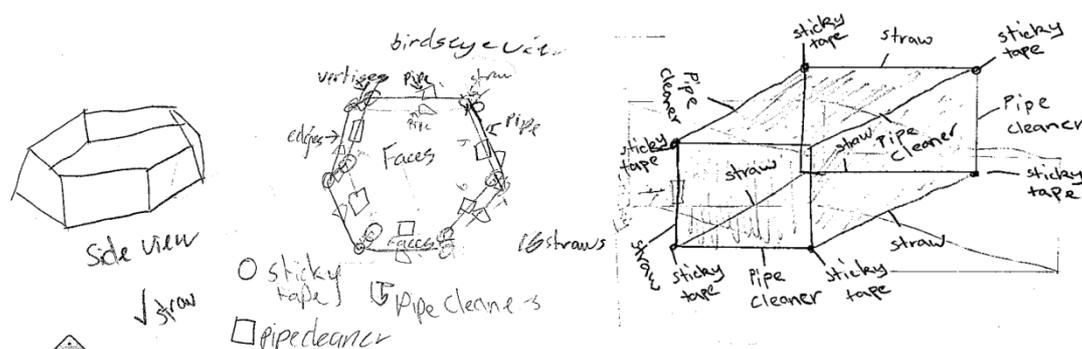


Figure 2. Examples of student outcomes: Labeled diagrams in the student workbook as a result of planning

Timetabling

As part of timetabling or scheduling STEM activities for students, the year 4 students were asked when they were most engaged in the series of STEM activities. Although this was met with mixed opinions, their comments focused mainly on when they were fully engaged with a hands-on activity such as designing, building, and testing the medical mission kit. One student suggested timetabling the activity before morning tea. However, as a matter of timing, students claimed they were least engaged when waiting for a hands-on activity, "Near the end when we had to complete the rest of the booklet", "when the teacher was explaining (sic) different ways we could design our shape" and "after morning tea when writing". When students ($n=19$) were asked about the length of the STEM activities (total five hours), ten claimed that it was long enough, six claimed that it was not long enough and only one said it was too long (two abstained).

The teacher made pedagogical decisions on timetabling and duration of activities; however research needs to uncover the rationale for such decisions. Evidence around student knowledge, understandings, skills and attitudes were not obtained as a link to timetabling. In

this study, the curriculum co-designers (researchers and teachers) wanted to scaffold conceptual development in science and mathematics towards the engineering activity, which is elaborated later within the content knowledge section.

Preparation

Preparation involved school staff undertaking the activities indicated in the Medical Mission teacher's guide. Preparation involved providing the teachers ($n=9$) from five different schools with the resources necessary to conduct the lessons, which included Information and Communication Technology (ICT, Youtube video and PowerPoint), stationery, materials for testing (e.g., aluminium foil, plastic, polyfoam), scientific and mathematical equipment (e.g., thermometer, weights, 30mL measuring cylinders) and a range of other resources such as ice, buckets with water and concepts from the student booklet.

As a skill-development outcome, the year 4 students were required to prepare and organise resources for designing, making and testing a medical kit. In the year 4 classroom under study, the teacher found that the booklets offered clear instructions and the teacher-designed PowerPoint reinforced the concepts towards preparing the students for the activity. Resources prepared for the unit were designed to motivate students for learning about the topic. The teacher noted student outcomes (e.g., values and attitudes; Athanasou & Lamprianou, 2002) through the "short duration videos [that] engaged students" for motivating them into the lesson. Preparation of resources was an essential element of teaching (see also Broek & Kendeou, 2008), particularly for STEM education activities that require hands-on materials for designing and constructing. The students in this class commented that the PowerPoint, as a prepared resource, provided them with "images...because if you couldn't understand a word the picture would help", a sequential order for the activities, an understanding of "what equipment I would be getting" and "helped me understand the Engineering Design Model". The resource preparation possibly motivated students into a positive attitude for engaging in the lesson.

The engineering design model (WGBH Educational Foundation, 2009) as a prepared resource presented students with content towards understanding an engineering design; although no evidence was gathered at this point to claim that the design model facilitated knowledge and understanding of STEM. However, students indicated that the Youtube videos assisted an understanding of the key concepts (e.g., what is matter and how it can change, what is a drone) required for undertaking the lesson. E-learning and using ICT tools such as Youtube can assist students in learning concepts (Duffy, 2008).

Teaching Strategies

Teaching strategies can involve the use of audio and visual aids (e.g., YouTube clips), individual and group work, hands-on (e.g., designing, making and testing the Medical Mission kit) and so forth to engage students in learning. In this study, two teaching strategies (visual aids and role play, Killen, 2013) emerged as favourable by both the teacher and students while views varied about individual work and group work. For instance, role play around the three states of matter appeared to instil positive attitudes into students about their learning as they said this was "fun learning" and "helped me understand how the different molecules and particles worked". The usefulness of role play as a teaching strategy has been recognised in academic works (McSharry & Jones, 2000).

In reference to individual and group work, the teacher claimed that overall students were “highly engaged when working independently on designs” but “some students seem a little hesitant/uncertain when working on their own – lack of confidence in own ideas”. The teacher indicated that although students “share ideas freely when in groups” there was also “some distraction when in groups”. Several students reported that group work “helped me to be more creative with my ideas” (as part of a skill development outcome) with a chance to “share different ideas” and “if one of us didn’t know the answer we could discuss it”. They commented that individual work had the following advantages: “thinking on our own so we could explore”, “more concentration”, “no complaints or distractions” and “it helped me learn that you don’t always need help”. It was noted that planning the student booklet with graphic organisers can be used as a resource and a teaching strategy allowed students to record their learning such as prior knowledge of testing properties of materials with experimental outcomes. However, student feedback suggested more visuals such as “video of kit being delivered”, “more pictures about medical mission”, and “more video to explain things”. Some students wanted less assistance from the teacher: “Let us work by ourselves” and “Less help”.

Prince (2004) suggested that there appears to be “broad but uneven support for the core elements of active, collaborative, cooperative and problem-based learning” (p. 223). In this current study, it seemed that as a student outcome (e.g., skill development and attitude) a combination of individual and group work may assist to target students’ learning needs, particularly as some students require group work for motivation and ideas while individual learners can forge their own directions for problem solving (Gokhale, 1995). Engineers work in groups and individually at various times; thus this method may provide a way to emulate the work of engineers. Overall, the teacher and students indicated that the teaching strategies employed during the STEM lessons facilitated positive attitudes in students to engage with the concepts and tasks.

Content Knowledge

The content knowledge within the Medical Mission activity involved scientific and mathematical concepts mainly based within the Australian Curriculum (ACARA, 2013). For example, one science concept was “Natural and processed materials have a range of physical properties; these properties can influence their use” (ACSSU074) and mathematical concepts were around measuring and comparing lengths, masses, capacities and temperatures (ACMMG084; ACARA, 2013). These concepts were used in the materials engineering task for designing, making and testing a medical mission kit.

In this unit, the teacher gave his year 4 students a content knowledge quiz to check their knowledge of temperature, matter, 3D shapes, and properties of 3D shapes prior to teaching. One question was: “What types of matter are there?” The responses from the quiz indicated that the students knew very little about matter. The teacher provided students with multiple opportunities to engage with the key concepts, including teacher explanations, videos and hands-on activities. One activity that sought to engage students in learning about the properties of materials was using a predict-observe-explain (POE) activity where students tested the properties of materials (e.g., aluminium, paper, polyfoam) to determine if they could be squashed, stretched, twisted or scratched. They also tested the materials to determine if they were waterproof, particularly for consideration of designing and making the medical kit design. Students were asked to predict what will happen by underlying “yes”, “unsure” or “no” and then observe the result by circling yes, unsure or no.

Figure 3 presents one student’s knowledge around the properties of materials, which showed there were 10 of the 25 testing of material properties that did not align with the

student’s prediction of the observation. The POE technique was intended to challenge students’ prior knowledge about phenomena (Liew & Treagust, 1995). The student was unsure if plastic would stretch but wrote it “easily stretches” after testing the plastic. Similarly, the student was unsure if polyfoam was waterproof but after testing was able to circle “no” and write “absorbs water”. The student may have demonstrated prior understandings about content knowledge where alignment between prediction and observation occurred. For instance, when testing whether the paper would be squashed, the student underlined and circled “yes” and wrote “when squashed it stays”. There were eight “unsure” prior knowledge responses prior to testing, which suggested the activity challenged the student’s existing knowledge about the properties of materials towards considerations for designing and constructing the Medical Mission kit.

Material	Squash			Stretch			Twist			Scratch it			Waterproof		
	Yes	Unsure	No	Yes	Unsure	No	Yes	Unsure	No	Yes	Unsure	No	Yes	Unsure	No
Aluminium (metal)	<u>Yes</u>			<u>Yes</u>			<u>Yes</u>			<u>Yes</u>			<u>Yes</u>		
	when it squashed it stays			and rips easily			easily twists			easily rips					
Paper	<u>Yes</u>			Yes	Unsure	<u>No</u>	<u>Yes</u>			<u>Yes</u>			Yes	Unsure	<u>No</u>
	when squashed it stays			when stretched it rips			and rips			got ripped			absorbs alot of water		
Plastic	<u>Yes</u>			<u>Yes</u>			<u>Yes</u>			<u>Yes</u>			<u>Yes</u>		
	goes back to original shape			easily stretches			goes back to original shape			it ripped					
Fabric	<u>Yes</u>			Yes	Unsure	<u>No</u>	<u>Yes</u>			Yes	Unsure	<u>No</u>	Yes	Unsure	<u>No</u>
	goes back to original shape			dose not stretch at all			get creased			didn't rip			absorbs water		
Polyfoam	<u>Yes</u>			<u>Yes</u>			<u>Yes</u>			<u>Yes</u>			Yes	Unsure	<u>No</u>
	goes back to original shape			rips easily			goes back to original shape			it rips after a while			absorbs water		

Figure 3. Testing the properties of materials

Students provided responses to a posttest questionnaire and interviews that focused on student outcomes (in this case, knowledge and understanding). Expectedly, various responses indicated more content knowledge around the key concepts taught compared with the pretest. There were responses that included understandings about a material engineer’s work and the purpose of a prototype with science understandings around the three states of matter and freezing/boiling points of water. Mathematics understandings were indicated around naming the properties of 3D shapes and recording temperature. Importantly, students connected their understanding of the property of materials with choices for the design task represented by comments such as: “gave us an idea of what was the best material to use” and being involved in an engineering activity: “gave me the logic I needed to work out the results”. Content knowledge about the properties of materials may have been formed as a result of the Medical Mission activity outlined in the student booklet.

Problem Solving

Problem solving as a pedagogical practice attempts to be pre-emptive in the planning and preparation stages to negate potential problems when teaching in the classroom (Lampert, 1985). The co-designers of Medical Mission discussed particular problems that could emerge as students engage in the activities from fine-motor coordination tasks, timing of the experiment, and gauging student abilities. For instance, students were expected to use pipe cleaners as a frame for a 3D structure, however, one researcher (English) noted from another school that “quite a few had fine-motor problems” when it came to using pipe cleaners, especially joining the ends of pipe cleaners, which was an unanticipated problem for the teacher to resolve. In addition, there was a timing difficulty when testing the insulation properties of the medical kits that is, timing how long it took ice cubes to melt in the sun as a control compared with the ice cube in the medical kit.

Problem solving occurred when the year 4 teacher noticed it was taking too long for the small ice cube to melt in the sun and so took the students inside to complete one part of the student booklet. A subsequent solution was put forward by a researcher (English) that the students “could have compared one another's creations while waiting”. It appeared that some potential problems may have been diverted as a result of pre-emptive planning. For example, the co-designers of the program discussed the potential difficulty of using syringes as water measures, which was then emphasised with the teachers ($n=9$) during the trial run.

Catering for the range of student abilities involved pedagogical problem solving, as some students required further teacher support during the constructing stage. The classroom teacher suggested that when there was “disappointment with a design that didn't turn out as planned, I tried to encourage the student to see that failure is a step in learning and shows that they are trying; also an opportunity to learn from and redesign with the failure in mind”. Although the focus was on problem solving as a pedagogical practice, the students also noted that problem solving was required at different points during the activities that may require teacher intervention. For example, when making the medical kit the “pipe cleaner not strong enough [so I] put straw over it”, “How to put straws on corners - bent pipe cleaners” and “Keeping the ‘skeleton’ of shape in its correct form – I held it”. Also problem solving was required during teamwork: “Our group had different answers but redid the activity to get it right”. Teachers need to be solution seekers when issues and problems arise in the classroom and being aware of students' problems may also provide an understanding of problem solving as a pedagogical practice. Lampert (1985) explains that “our understanding of the work of teaching might be enhanced when we explore what teachers do” when they are involved in classroom problem solving (p. 194).

Classroom Management

The Medical Mission activity may have engaged the students to minimise potential classroom management issues. The classroom teacher observed and wrote that students were engaged in the activities by “testing of materials, construction of kits, [and] watching clips”. However, the teacher noted that the students lost focus when there was “too much reading/speaking” and when they were “required to listen to instructions too long” and “required to formalise findings”. The students indicated that they were more engaged (and managed effectively) when role playing states of matter, watching the videos of engineers, testing the materials, and designing and constructing a medical mission kit.

This school was a single-gender private school and classroom management issues were at a minimum during the activities. For instance, in a correlational study design Zimmer and Toma (2000) analyse the peer effects in private and public schools across five countries

with an analysis indicating that “peer effects are a significant determinant of educational achievement; the effects of peers appear to be greater for low-ability students than for high-ability students” (p. 75). Determining whether the STEM activity assisted in managing the single-gender class from a private school would require comparisons with schools from other contexts. Nevertheless, the current study found that the designing, constructing and testing of a medical mission kit facilitated student engagement and, as such, may have contributed to effective classroom management.

Questioning

Dillon and Dillon (1988) outlined the necessity for effective questioning (formal and informal) to facilitate learning. The year 4 teacher in this current study was asked: How did questions help the students to understand the concepts and their tasks? The teacher explained that questions prompted mathematical language usage such as “vertices” instead of “corners” and allowed the students to “formulate their purpose/decisions/choices”. In addition, the teacher explained a range of questions used during the lessons, including knowledge, analytical and evaluative questions such as “Why have you chosen this?” and “What will happen if...?” that encouraged the students “to justify their actions/thoughts”. The teacher suggested that these questions facilitated deeper thinking.

Students commented on the questioning used during the Medical Mission activities for which they claimed encouraged reflection on work; for instance one of the questions “asked what might happen which helped me think about design more”. The teacher noted student outcomes when they could articulate knowledge and understandings around the questions. However, the students pointed out that they lost interest when they were asked to respond to questions when they previously knew the answers.

The questions devised for the activities in this current study were initially based on Bloom’s taxonomy (1956) by one researcher (Hudson) before submitting the work to the team for further input. However, the questions did not take into account other questioning methods such as Well’s (1993) three-turn method or Blank’s (1968) questioning techniques for abstract thinking. There were questions devised that attempted to elicit reflective thinking though not to the extent advocated by Minstrell (1982). Although a study (Smart & Marshall, 2013) has shown that questions at different levels of complexity result in positive correlations with the level of student engagement, the current study did not measure such a relationship. In addition, the notion of coaching for reflective teaching (Schön, 1987) during the trial period with teachers involved in the Medical Mission program could have extended to discussions around reflective questions for students (Van Zee & Minstrell, 1997).

Implementation

Implementation of the lesson includes the lesson structure (introduction, body and conclusion) and the sequence of activities to support the design, make and testing of the Medical Mission kit. The year 4 teacher reflected on the implementation with comments that aimed to advance the lesson structure. For instance, he believed he needed a “more engaging introduction for greater impact” and that the conclusion was “a little rushed” where the inclusion of “some type of overall table or data representation that might be used to determine the most effective design”. Two students reported that the sequence of lessons (as part of implementation) assisted in selecting materials and recording results, which may be noted as a student outcome.

It was uncertain if the lesson structure for implementation in this current study had a direct effect on student outcomes, particularly as there was no assessment in the introduction of the lesson. It was also not determined if the implemented sequence of activities provided an optimum arrangement. Studies nearly three decades ago provided some insight into lesson structure for implementation and effects on pedagogical knowledge practices such as questioning. For instance, Smith (1985) conducted a correlational study on lesson structure, questioning and student achievement in the social sciences. He showed that “Lesson structure affected scores for lower level questions but had little effect on scores for higher level questions” (p. 44). Another study (Fauth, Decristan, Rieser, Klieme, & Büttner, 2014) showed that student ratings of teachers’ implementation of lessons, which considered classroom management can predict student achievement, while facilitating a supportive climate and cognitive activation can predict students’ interests in the subject. However, further studies are needed to investigate how the implementation of a lesson structure affects student outcomes in STEM education and how to most effectively implement activities that may lead towards successful engineering education designs.

Assessment

Assessment was initially considered to be located in the work samples (i.e., designing, making and testing the medical mission kit and students’ completion of worksheets). Also students reported they learnt that “material engineers find out about different materials”, “matter is solid, liquid, gas”, “molecules make matter” and “polyfoam is good at keeping things cool”. Some students made mention of their science learning (states of matter and molecules), some commented about their learning of 3D shapes when considering the frame of the medical kit (e.g., “names of 3D shapes – square based pyramid”), and all provided outputs around the engineering activity, such as selecting materials for constructing the medical kit. In mathematics, students recorded their knowledge and understanding of vertices, edges and faces of different 3D shapes and of the properties of materials in the student booklet. The teacher commented that students’ outcomes were apparent in how they engaged with the student booklet: “The girls’ illustrated designs were detailed and quite sophisticated”, which led to the 3D construction (Figure 4). The student booklet allowed students to write explanations around their choice of materials, the effectiveness of their designs, and conclusions drawn from testing their designs.

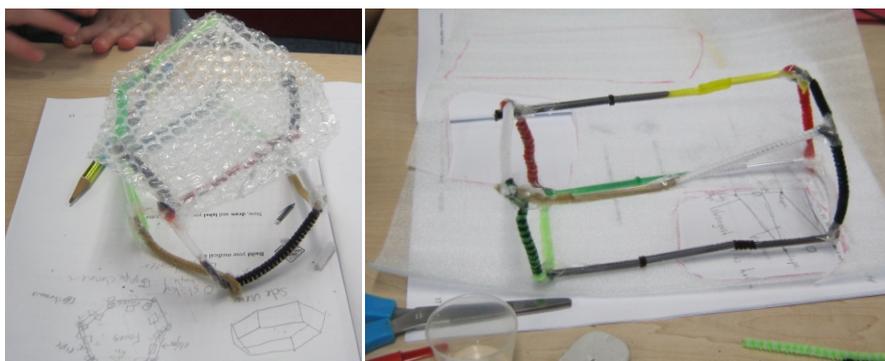


Figure 4. From labelled diagrams to 3D construction

Although basic principles for assessment were considered (explicit criteria, identifying achievements, and gathering verifiable evidence of learning; e.g., Harlen, 2004), there was difficulty in differentiating assessment in the making and testing of the medical mission kits. A pretest provided some diagnostic understandings for targeting students' learning needs (Athanasou & Lamprianou, 2002), though the program was pre-determined and further differentiation was not included; instead differentiation was left up to the teacher's initiative in catering for the various learning needs. In a formative assessment way, student outcomes were shown in the conceptual development stages (mathematics and science) within their booklets, however a stronger self-assessment component could have been adopted (e.g., Black & Wiliam 1998). Further advancements in planning for assessment of learning could have included assessment rubrics to locate differentiated outcomes (Hudson, 2005).

Viewpoints

As mentioned previously, there are individual viewpoints on teaching any lesson. Pedagogical viewpoints extend to what the teacher may consider valuable in terms of achieving student outcomes. In this study, viewpoints were articulated by the co-designers (including teacher input) for the Medical Mission program. These pedagogical viewpoints incorporated the types of activities, sequence of activities, assessment and evaluation opportunities and expectations for student involvement in the activities. There were viewpoints around how to sequence the activities to optimise student outcomes, which lead to dividing the program into two parts (i.e., Part A for conceptual development and Part B for the engineering activity drawing on the conceptual understandings). There were also viewpoints on assessment and evaluation opportunities, which lead to developing a self-evaluation rubric for students to complete at the end of the Medical Mission program. Students were expected to be engaged in all aspects of the program.

The year 4 teacher had viewpoints on different methods for engaging students in the activities. For instance, he used accessible equipment for demonstrating concepts about 3D shapes and tried to relate the shapes to real-world examples. The teacher wrote: "Tried to use equipment like a metal pencil case at student's desk to help predict where weak/strong points may be found in this particular shape" and "Had students look at other real-life and nearby shapes to see commonly used shapes and also those not so common". These viewpoints facilitated an initiative for making the activity more relatable to the real world by having "students dress up for the day as further novelty and to gain further enthusiasm". Indeed, the students and the teacher were dressed in commando-mission attire (army camouflage green

and black) as “some attempt to provide a scenario/setting – though I would like to do more with this next time e.g., more interactive and use of video/characters”.

The teacher’s methods indicated his viewpoints on how to enact the Medical Mission activities. For analysing the teacher’s pedagogical viewpoints from the students’ perspectives, students responded that the teacher assisted when he:

- Walked around, asked questions – made us reflect and think about what we were doing.
- Sat down spoke about what might happen and how we might fix it.
- Checked if we were clear with things.
- Described things clearly.
- Used a ppt [PowerPoint] with pictures, gave order.
- Gave ideas/tips.
- Never said ‘you are wrong’.
- Said it was ok when the design collapsed.

The teacher’s viewpoints for teaching became transparent when analysed through the student lens. That is, questioning, monitoring student activities, providing suggestions on advancing designs, clarity of explanations, visual and auditory assistance, and re-affirming student work tended to be the *modus operandi* for this particular year 4 teacher. Student comments indicated that some were visual learners and some wanted to be more independent in their learning. Students indicated individuality and despite a student saying it helped when the teacher “Never said ‘you are wrong’”, another student commented that she would have learnt more if the teacher had “Shown me what I was doing wrong in my design”. Although this study did not investigate how the teacher’s viewpoints were shaped, there were indications that the teacher’s viewpoints translated into teaching practices that varied from the Medical Mission teacher guide. This has implications for designers of STEM education programs where such programs need to allow flexibility to include teachers’ viewpoints on teaching the material, particularly as they have knowledge of the classroom context.

Study Limitations and Further Research

This study attempted to investigate possible links between 11 pedagogical knowledge practices and student outcomes within a STEM education unit of work. Although the pedagogical knowledge practices are statistically interrelated (Hudson et al., 2005), understanding the relationship between each of the practices was not included in this study. Indeed, teachers may not necessarily differentiate between the practices, for example, they are often assessing while they are teaching when using multiple teaching strategies. The study did not provide a full picture of each practice but rather examples of student outcomes that may be associated with a particular pedagogical knowledge practice. The study did not provide an evaluation of the Medical Mission activities to determine all student outcomes but instead singled out specific pedagogical knowledge practices for the purposes of linking these practices to particular student outcomes such as knowledge, skills, and attitudes. Nevertheless, effective STEM education will require teachers to link pedagogical knowledge practices to student outcomes.

As initially mentioned, student outcomes can be noted through knowledge and understanding, skill development, and values and attitudes (Athanasou & Lamprianou, 2002; Brady & Kennedy, 2001). Students’ knowledge about science and mathematics concepts was evident within the student booklet (3D shapes; temperature; states of matter; testing the properties of materials). Although designing and constructing the medical kit may be considered skill development, the science and mathematics inquiry skills such as working

with a problem, deciding on resources and experimental set up along with minor manipulative skills in constructing the medical kit require further investigation. Yet, the students' values and attitudes were apparent in the way they interacted with the activities.

Although the pedagogical knowledge framework has been used in other contexts (e.g., mentoring for teaching in mathematics and science), more studies are required around pedagogical knowledge practices to understand how it influences student outcomes in STEM education. Each component of the pedagogical practice framework can be investigated to understand how teaching influences student outcomes. For example, studies can: (1) align teaching strategies to STEM activities that elicit particular student outcomes; (2) determine effective questioning techniques to facilitate student conceptual development in STEM education; (3) present methods for assessing students' STEM education achievements; and (4) investigate how teachers' viewpoints can influence the learning environment for STEM education. As the pedagogical knowledge practices are interrelated statistically and empirically (Hudson et al., 2005), further investigations could indicate how each practice contributes to another practice (e.g., teaching strategies and content knowledge; questioning and assessment; planning and classroom management) for STEM activities.

Conclusion

The study showed how pedagogical knowledge practices may be linked to student outcomes (knowledge, understanding, demonstration of skills, and values and attitudes) for a STEM education activity. For instance, "planning" involved devising a student booklet as a resource for students to understand the tasks required of them for designing, constructing, and testing a medical mission kit. The mathematics and science concepts were embedded in the planned resources to aid students' understandings of the engineering activity. However, the degree of outcome attainment needs further investigation such as links between students' learning of science and mathematics concepts and the teacher's pedagogical choices. As an implication for advancing STEM education programs, the framework (Figure 1) may be used to evaluate teaching practices to help teachers plan more effectively for students. This framework can assist researchers to identify the effect of pedagogical knowledge practices on influencing student outcomes. STEM education is a relatively new field for primary education in Australia and elsewhere, which warrants substantial investment into research on how STEM education can elicit and verify student outcomes.

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Acknowledgements

The project reported here is supported by a three-year Australian Research Council (ARC) Linkage Grant LP120200023. Any opinions, findings, and conclusions or recommendations expressed in this paper are those of the authors and do not necessarily reflect the views of the ARC. We wish to acknowledge the excellent support provided by our research assistants, Lorraine English, Lyn Nock, and Jo Macri.