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Analysing preservice teachers' potential for implementing engineering education in the middle school

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Summary: Engineering is pivotal to any country's development. Yet there are insufficient engineers to take up available positions in many countries, including Australia (*Engineering Australia*, 2008). Engineering education is limited in Australia at the primary, middle, and high school levels. One of the starting points for addressing this shortfall lies in preservice teacher education. This study explores second-year preservice teachers' potential to teach engineering in the middle school, following their engagement with engineering concepts in their science curriculum unit and their teaching of engineering activities to Year 7 students. Using a literature-based pretest-posttest survey, items were categorised into four constructs (i.e., personal professional attributes, student motivation, pedagogical knowledge, and fused curricula). Results indicated that the preservice teachers' responses had not changed for instilling positive attitudes (88%) and accepting advice from colleagues (94%). However, there was statistical significance with 9 of the 25 survey items (p<.05) after the preservice teachers' involvement in engineering activities. Fusing engineering education with other subjects, such as mathematics and science, is an essential first step in promoting preservice teachers' potential to implement engineering education in the middle school.

Keywords: engineering education, middle school, science, mathematics

INTRODUCTION

More than 20,000 engineers are required in Australia to fulfil shortfalls, and despite the availability of university degrees there appears insufficient uptake to cater for Australia's needs (Taylor, 2008). The number of graduating engineers has not increased significantly over the past 5 years (King, 2008). Some claim that engineering can be taught at the early school levels, as there are fundamental concepts that can be included in mathematics, science, and engineering (Miner, 2004; Oware et al, 2007). Fusing curricula such as science and mathematics as a way to further engineering education may also benefit middle-school students' learning in science and mathematics (Cantrell et al, 2006). Evidence suggests that engineering activities have enhanced learning in mathematics (English & Mousoulides, 2009; Sharp et al, 2006). Yet, engineering education is limited in Australia at the primary, middle, and high school levels. Australian education systems do not target students who may be suited to, and interested in engineering, and do not provide content knowledge or contextual knowledge for engaging them in engineering activities. Preservice teacher education is a foundational starting point for developing engineering education.

Four constructs have been identified and considered to be fundamental in developing preservice teachers' potential for implementing engineering experiences in the classroom, namely, personal professional attributes, student motivation, pedagogical knowledge, and fused curricula (Hudson, et al, 2009). With respect to the first construct, teachers need personal attributes within a professional environment that help to facilitate learning (Banner & Cannon, 1997; Vallance, 2000). Effective teachers display a self efficacy or confidence to teach (Bandura, 1997; Pajares, 1997). The relationship between self efficacy and confidence has been explored in science (Enochs & Riggs, 1990) and mathematics (Enochs et al, 2000), concluding that confidence and self efficacy are inextricably linked. There is also a relationship between teaching any subject matter and the teacher's attitude towards delivery of the subject (Nieswandt, 2005). Indeed, teachers who have a positive attitude towards teaching a subject can influence a student far more than one who has a negative attitude (Ediger, 2002). This positive attitude may be noted when the teacher displays enthusiasm for the subject. Numerous studies have shown that students are far more engaged in lessons where the teacher displays enthusiasm (see Tauber & Mester, 2006). In addition, effective teachers reflect on their practices for improvement (Gurney, 2007; Luehmann, 2009; Schon, 1983), part of which is seeking and accepting advice from colleagues and other professionals who can enhance their practices. Effective teachers update their content knowledge to assist students by advancing current understandings on topics and key concepts (Hudson, 2006; Lenton & Turner, 1999). Personal attributes that display a willingness to research and learn about current educational innovations can advance a practitioner's pedagogical position.

In light of teaching engineering at the school level, a teacher's pedagogical knowledge is considered key for facilitating learning (Hudson & Ginns, 2007). A teacher must be able to plan for teaching the subject through a range of tasks including hands-on activities to cater for different learning styles and foster deeper learning. This requires the selection of appropriate equipment and resources relevant to the students' needs. This plan needs to encompass a variety of teaching strategies to aid in structuring an environment that encourages students to learn (Hassard, 2004). Effective learning environments present a range of opportunities for both collaborative and independent studies. A key role for the teacher while activities are being implemented is the use of effective questioning (Skamp, 2007). Current educational advancements indicate that questioning techniques can mirror theoretical underpinnings to engage levels of thinking. For example, Bloom's Taxonomy with the six levels of thinking (knowledge, comprehension, application, analysis, synthesis, and evaluation) can be used to shape and deliver effective questioning before, during, and after student activities (Starr et al, 2008). Higher-order thinking questions (i.e., analysis, synthesis, and evaluation) can stimulate students' thinking processes (Anderson & Krathwohl, 2001). Similar to teaching other subjects, this fundamental pedagogical knowledge must be in place for teaching engineering education.

Student motivation is also a key component in introducing school students to engineering experiences. Teachers need to know how to motivate students for learning in the subject area (Pintrich, 2003). This requires instilling positive attitudes to motivate students towards engineering, which can encourage them to consider engineering as a career option (Cheng, 2008). Although there are many ways to motivate students, who have different internal mechanisms for self motivation, a teacher implementing engineering education can motivate students by: (1) targeting their misconceptions about the topic or key concepts (Broek & Kendeou, 2008); (2) facilitating cooperative group work with interactive activities (Howe et al., 2007); (3) providing practical and useful activities (Skamp, 2007); and (4) presenting students with real-world excursions related to the topic being studied (Hudson, 2007). Assessing students' learning of concepts and processes, and evaluating the teaching and learning environments must also be part of engineering education.

Finally, fusing curricula such as science and mathematics can further engineering education for middle-school students (Cantrell et al., 2006). To illustrate, understanding scientific principles of buoyancy and mathematical formula for volume can assist in designing a boat that floats. In addition, fusing mathematics and engineering can advance students' learning in mathematics (English & Mousoulides, 2009; Sharp et al., 2006). For example, engineering-based modelling activities, which we refer to later, engage students in quantifying information, combining qualitative and quantitative information, and applying decision-making approaches. Furthermore, the acronym, STEM, highlights the fusing of curricula between science, technology, engineering and mathematics, and has been noted as an area of need in Australia (Tytler et al., 2008). There are numerous fundamental concepts that can be fused across these domains.

In summary, the research aim of this study was to investigate preservice teachers' potential for implementing engineering education in the middle school. The aforementioned four constructs (personal professional attributes, student motivation, pedagogical knowledge, and fused curricula) formed the framework for addressing this aim.

METHODOLOGY

Participants

This study involved 17 second-year preservice teachers at an Australian regional university campus at the beginning of their first science education curriculum unit. There were 3 males and 14 females, with a little less than half being mature-aged preservice teachers. Demographics obtained from the survey showed that no preservice teacher in this cohort had life experiences involving engineering; however preliminary survey information showed that 29% claimed mathematics was a favourite subject and 47% claimed science as a favourite subject. There were four preservice teachers who recorded both mathematics and science as a favourite subject.

These preservice teachers had been involved in a mathematics and science discipline unit in first semester of their second year, which focused on science and mathematics content knowledge. To understand their development to date, their first year of first semester units included an introduction to education, teaching in new times, and learning networks using computers, while second semester units involved visual and verbal literacy, Indigenous education, active citizenship and wellness, health and physical education. The preservice teachers had received no practical school experiences in their first year of their course.

Learning Experiences

The preservice teachers' one-semester science pedagogy course involved a one-hour lecture, a one-hour tutorial, and a two-hour workshop each week. Lecture topics included: Constructivism; Conceptual change; Problem-based inquiry; Curriculum and instructional designs; Fusing curricula; Assessment and evaluation; and Designing science units of work. The tutorials concentrated on planning science lessons and science units of work while the workshops allowed for multiple hands-on experiences and first-hand scientific investigations across a wide range of topics (e.g., Earth science, astronomy, weather, life and living, natural and processed materials).

Pairs of preservice teachers also devised and organised a science lesson that they taught to their peers, who subsequently provided anonymous written feedback (positive aspects of the lesson and aspects that require improvement). Both the science unit of work and lesson presentations were assessed as part of the coursework. Activities in tutorials and workshops highlighted a lesson structure, teaching strategies, questioning techniques, classroom management, and the use of technologies to facilitate hands-on science lessons.

Preservice teachers were scaffolded towards implementing engineering activities with Year 7 students in two science workshop sessions with a science education academic, an engineering academic, and four engineering undergraduate students. The preservice teachers were provided with key scientific and mathematical concepts around two engineering activities (i.e., building bridges and floating a boat). For building bridges key concepts included tension and compression forces, while the floating a boat activity worked on density and the mathematics formula (d=m/v). The preservice teachers were also presented with a brief lesson plan that they could adapt or amend as required. Indeed, many preservice teachers advanced these lesson plans in their own time by including other resources and other ideas around the key concepts.

DATA COLLECTION AND ANALYSIS

Pretest-posttest responses were recorded on a five-part Likert scale (strongly disagree to strongly agree and scored 1 to 5, respectively). The survey was administered as a pretest at the beginning of the preservice teachers' science education coursework and then as a posttest at the end, after they had conducted engineering activities with Year 7 students. The 25-item survey was designed within four constructs providing the framework for this study, *a priori*, to assist in preliminary confirmatory factor analysis (CFA), (Kline, 1998). Items from the survey (Appendix 2) were assigned to the following factors:

Factor 1: Personal professional attributes – survey items 2, 3, 6, 11, 21
Factor 2: Student motivation - items 4, 10, 14, 18, 22, 24
Factor 3: Pedagogical knowledge - items 5, 8, 9, 12, 13, 15, 17, 19, 23
Factor 4: Fused curricula - items 1, 7, 16, 20, 25

Using SPSS, data were subjected to data reduction by assigning items to a construct (i.e., factor). The pretest involved 36 second-year preservice teachers which provided an indication of instrument reliability. That is, these factors with associated items were tested for internal consistency using a reliability measure, Cronbach alpha, where scores over .70 are considered acceptable (Kline, 1998). These steps were repeated for each of the four factors. Hence, data from the survey describe aggregated patterns instead of building causal relations (Creswell, 2008). SPSS was used to examine if one or more factors existed, and Cronbach alpha scores provided reliability for these factors. Through a confirmatory factor analysis, eigenvalues >1 were a measure to determine the number of factors extracted. This means that items on the survey were assigned to factors (as indicated above) and SPSS generated eigenvalues for each proposed factor. More than one eigenvalue or an eigenvalue <1 would render the items with the assigned factor as statistically incompatible (Kline, 1998). Also scale mean scores were recorded with standard deviation for each factor by using "compute variable" in SPSS. The outcome of this pretest investigation (n=36) showed that only one factor was extracted for three of the four constructs. The pretest results are shown in Table 1.

Table 1: CFA, Eigenvalue and Cronbach alpha scores (n=36)

Factor	*M* scale score	*SD*	Eigenvalue	% of Variance	Cronbach alpha
Personal professional attributes	3.62	0.84	3.40	68.1	0.88
Student motivation	3.69	0.79	4.19	70.0	0.91
Pedagogical knowledge	3.44	0.78	5.40* 1.06*	60.0 11.8	0.91
Fused curricula	3.43	0.78	3.47	69.3	0.89

*Two factors extracted for pedagogical knowledge

Despite participant numbers being too small to provide data accuracy, it gave an indication of a relationship between the items and associated constructs. Hence, these same constructs and associated items were maintained. Surveys were returned anonymously with mother's maiden name as the only identification. Although the posttest was provided to the 36 participants, only 17 returned with a mother's maiden name identification that could be matched to the pretest. Nevertheless, an ANOVA could be conducted with each pretest-posttest pair of items (i.e., *t*-test and *p* value, two-tailed significance; *n*=17). Using SPSS, a pretest item was entered with a posttest item for comparing means using a paired-samples *t*-test. Descriptive statistics (percentages, mean scores [*M*], standard deviations [*SD*]) were used to explain each item.

RESULTS AND DISCUSSION

Pretest-posttest data were analysed within the four proposed constructs (i.e., personal professional attributes, student motivation, pedagogical knowledge, and fused curricula). Findings indicated that preservice teachers' perceptions of their personal professional attributes had increased significantly with most items, as a result of their coursework and teaching experiences. For example, preservice teachers' perceptions of enthusiastically facilitating engineering lessons and confidently teaching engineering increased (60% to 88%, p=0.08; 18% to 77%, p=0.01, respectively; Table 2). Accepting advice from colleagues had no increase as response rates were already high in the pretest. Although having confidence to teach engineering was the highest percentage increase it was the lowest percentage in the posttest items within this construct (Table 2). Only one item associated with the construct student motivation were statistically significant in the posttest (cooperative group work, p=0.02). One item did not change from pretest to posttest (instil positive attitudes, 88%). Eighty-eight percent of these preservice teachers believed they could motivate students into engineering education in the posttest scenario (Table 2).

Table 2: Personal Professional Attributes and Student Motivation for Teaching Engineering

Item with associated construct	Pretest (*n*=17)				Posttest (*n*=17)			ANOVA	
	M	*SD*	%*		*M*	*SD*	%*	*t*-test	*p* value
Personal professional attributes									
2. research a range of ideas	3.77	0.75	59		4.00	0.61	82	-0.94	0.36
3. enthusiastic, facilitate lessons	3.65	0.79	60		4.00	0.50	88	-1.85	0.08
6. accept advice from colleagues	4.41	0.71	88		4.41	0.62	94	0.00	1.00
11. confidently teach engineering	2.94	0.66	18		3.82	0.53	77	-3.92	0.01
21. have a positive attitude	4.06	0.66	82		4.18	0.64	88	-0.70	0.50
Student motivation									
4. targeting misconceptions	3.59	0.87	59		3.94	0.56	82	-1.46	0.16
10. for learning engineering	3.94	0.66	76		4.18	0.64	88	-1.17	0.26
14. instil positive attitudes	4.00	0.50	88		4.00	0.50	88	0.00	1.00
18. cooperative group work	3.65	0.61	59		4.12	0.49	94	-2.70	0.02
22. practical, real-world activities	3.88	0.60	77		4.18	0.64	88	-0.90	0.38
24. real-world excursions	3.82	0.81	59		4.18	0.53	94	-1.56	0.14

* = percentage of agreed and strongly agreed responses

Pedagogical knowledge for teaching engineering had statistical significance for eight of the nine associated items (Table 3). Of particular note was the increase in their perceptions of being able to select appropriate equipment and resources (41% to 94%, $p<.01$), to guide students into independent studies in engineering (41% to 88%, $p<.01$), and to work with students in solving engineering-based problems (47% to 88%, $p<.01$; Table 3). Yet, using effective questioning strategies when facilitating engineering lessons had no significant increase, as percentages were high in the pretest. This suggests that preservice teachers may recognise that questioning strategies are transferable from one subject to the next. Indeed, these preservice teachers were involved in science education coursework that included Bloom's Taxonomy as a way to question towards lower and higher-order thinking.

Engineering fuses curricula. It uses mathematics and science as a basis for understanding engineering. For the fused curricula construct, pretest responses were between 41% and 65% for each of the five items; yet the posttest responses were statistically significant for three of these items ($p<.05$, Table 3). Percentages doubled or more than doubled from the pretest to posttest for applying mathematics concepts and using technology for understanding engineering.

Table 3: Pedagogical Knowledge and Fused Curricula for Teaching Engineering

	Pretest				Posttest			ANOVA	
Item with associated construct	*M*	*SD*	%*		*M*	*SD*	%*	*t*-test	*p* value
Pedagogical knowledge									
5. effective questioning strategies	3.88	0.86	71		4.00	0.50	88	-0.57	0.58
8. appropriate equipment/resources	3.41	0.51	41		4.06	0.43	94	-4.40	0.00
9. variety of teaching strategies	3.65	0.70	53		3.88	0.49	82	-0.94	0.36
12. independent studies	3.41	0.51	41		3.94	0.43	88	-3.50	0.00
13. evaluate my teaching	3.71	0.85	70		3.71	0.49	82	-0.82	0.42
15. Address students' questions	3.24	0.83	35		3.94	0.42	88	-3.17	0.01
17. plan for teaching activities	3.59	0.79	53		3.94	0.56	82	-1.56	0.14
19. solve problems	3.47	0.51	47		3.88	0.33	88	-3.35	0.00
23. assess students' learning	3.47	0.72	59		3.88	0.60	88	-1.95	0.07
Fused curricula									
1. apply mathematics concepts	3.48	0.62	41		3.94	0.56	82	-2.43	0.27
7. apply science concepts	3.71	0.59	65		4.06	0.66	82	-1.69	0.11
16. identify the mathematics	3.59	0.62	53		4.06	0.43	84	-2.70	0.02
20. identify the science	3.59	0.61	53		4.00	0.00	100	-2.75	0.01
25. use of technology	3.53	0.72	41		4.06	0.43	84	-2.50	0.02

* = percentage of agreed and strongly agreed responses

CONCLUSION

This study aimed to investigate preservice teachers' potential for teaching engineering in the middle school, following their engagement with engineering concepts in their second year science curriculum unit. The posttest percentages indicated that preservice teachers believed they may be able to teach engineering if supported with content knowledge and real-world applications. Based on four constructs (i.e., personal professional attributes, student motivation, pedagogical knowledge, and fused curricula) these preservice teachers showed potential for teaching engineering at the middle school level. There also appeared transferability of items regardless of teaching one subject or another (e.g., accepting advice from colleagues and instilling positive attitudes in students), which could aid the development of engineering education.

As world technology progresses with society's need increasing, countries are rethinking engineering education (e.g., Crawley et al, 2007). Engineering is beginning to locate itself within classroom applications (Brophy et al, 2008), such as the inclusion of engineering-based model-eliciting problems within the mathematics and science curricula. Here, students are presented with real-world engineering situations in which they repeatedly express, test, and refine or revise their current ways of thinking as they endeavour to create a structurally significant product—namely, a model that can be used to interpret, explain, and predict the behaviour of one or more systems defined by the problem (English, 2008; Mousoulides et al, 2008).

Identifying preservice teachers' potential for teaching engineering can be advanced by understanding the practical applications of teaching engineering. Even though the senior level may provide better academic preparation with more positive attitudes towards engineering (Dawes & Rasmussen, 2007), middle schooling also appears to be an appropriate place for engineering education, which can be integrated within the mathematics, science, and technology curricula, Whether the inclusion of engineering education in just one of these curricula is more effective than fusing across curricula, remains an issue for further investigation. Nevertheless, the role of universities in facilitating engineering education will be pivotal to its development (Tafoya et al, 2005). Further investigation is required at fundamental stages for initiating engineering education, including preservice teachers' involvement at the middle school level.

As engineering incorporates a combination of subject concepts and principles, it may be overlooked as an educational endeavour within education systems. Engineering education must also be recognised in its own right as is the case in several US universities, such as Purdue, Virginia Tech and Washington State universities. Nevertheless, incorporating either engineering coursework within a degree or fusing engineering with other subjects may assist preservice teachers in implementing engineering education in their future classrooms. If school students are not aware of the scope of engineering and what it entails, education systems may be limiting students' career choices and contributing to the engineering crisis.

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Appendix 1

Science: NATURAL AND PROCESSED MATERIALS
Middle School: Year **7**

Building Bridges & Floating Boats (2 x 45 minutes)

Learning Outcomes:

Science (Queensland Studies Authority [QSA] Essential Learning) - Properties of a material will vary according to the type and quantity of components that make up its structure.

Mathematics (QSA Essential Learning) - Measurement involves error, which can be reduced through the selection and use of appropriate instruments and technologies.

Key Concepts for Engineering Activities:

Bridges **-** Materials used for making bridges need to be tested for compression and tension.

Boats **-** Buoyancy depends on density. The mass and volume of an object determines its density (d=m/v).

Safety: There are no foreseen out of the ordinary hazards associated with these two lessons (bridges & boats), other than safe use of scissors and sun protection if held outside.

Resources will be supplied (e.g., boats: plasticine, container, weights; bridges: straws, paddle pop sticks, tape).

Teaching and learning activities

Introduction: (≈10mins) Teachers provide a stimulus on the topic (i.e., either about building bridges or floating boats) with a selection of introductory, hands-on activities (e.g., www.TeachEngineering.org). Teachers question students about prior knowledge and understanding of these concepts and then ensure clarity of new terms (e.g., bridges – compression, tension; boats – buoyancy, density).

Body: (25mins) Students interact with hands-on activities (www.TeachEngineering.org). Teachers question on students' thinking processes and progress to higher-order thinking questioning towards the end of the task.

Conclusion: (5-10mins) The conclusion consolidates the key concepts. Students are asked to demonstrate these concepts (e.g., through discussion, diagram, practical demonstration, written statements).

Assessment: Teachers listen to students' articulation of key concepts (throughout the lesson and as noted in the conclusion). Work supplied by the students will also be assessed in terms of quality and understanding of key concepts.

Evaluation: Teachers reflect upon the students' learning experience, the learning environment, and their teaching practices with pertinent questions.

Extension: Students illustrate and label their products and write two accurate statements about their products. Other extension activities as determined by individual preservice teachers may also be included.

Appendix 2

Engineering in the Middle School

Please indicate the degree to which you agree or disagree with each statement below by circling only one response to the right of each statement.

Key: SD = Strongly Disagree D = Disagree U = Uncertain A = Agree SA = Strongly Agree

When implementing engineering education in the middle school, I would be able to:

1.	apply mathematics concepts to engineering-based activities...…….	SD	D	U	A	SA
2.	research a range of innovative engineering ideas. ………………..	SD	D	U	A	SA
3.	enthusiastically facilitate engineering lessons. ……………………	SD	D	U	A	SA
4.	motivate students by targeting their misconceptions about engineers and engineering.	SD	D	U	A	SA
5.	use effective questioning strategies. …………………………..…..	SD	D	U	A	SA
6.	accept advice from colleagues/the research team for teaching engineering.	SD	D	U	A	SA
7.	apply science concepts to engineering-based activities. …………....	SD	D	U	A	SA
8.	select appropriate equipment and resources for teaching engineering.	SD	D	U	A	SA
9.	use a variety of teaching strategies for students' learning in engineering.	SD	D	U	A	SA
10.	motivate students for learning about engineering. …….……..……	SD	D	U	A	SA
11.	confidently teach an engineering activity to my colleagues.	SD	D	U	A	SA
12.	present students with opportunities for independent studies in engineering.	SD	D	U	A	SA
13.	evaluate my engineering teaching. ………………………………..	SD	D	U	A	SA
14.	instil positive attitudes to motivate students towards engineering.	SD	D	U	A	SA
15.	address students' questions about engineering. ………………….	SD	D	U	A	SA
16.	show students how to identify the mathematics in engineering. …	SD	D	U	A	SA
17.	plan for teaching engineering-based activities. …………..….……	SD	D	U	A	SA
18.	facilitate cooperative group work to motivate students in engineering activities.	SD	D	U	A	SA
19.	solve problems that might arise within engineering lessons. …….	SD	D	U	A	SA
20.	show students how to identify the science in engineering. ………...	SD	D	U	A	SA
21.	have a positive attitude towards teaching engineering. ……..……..	SD	D	U	A	SA
22.	motivate students through practical, real-world engineering activities.	SD	D	U	A	SA
23.	assess students' learning of engineering concepts and processes.	SD	D	U	A	SA
24.	motivate students in engineering through real-world excursions. ….	SD	D	U	A	SA
25.	facilitate students' use of technology for understanding engineering.	SD	D	U	A	SA