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INTEGRATING ENGINEERING EDUCATION WITHIN THE ELEMENTARY AND MIDDLE SCHOOL MATHEMATICS CURRICULUM

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Many nations are experiencing a decline in the number of graduating engineers, an overall poor preparedness for engineering studies in tertiary institutions, and a lack of diversity in the field. Given the increasing importance of mathematics, science, engineering, and technology in our world, it is imperative that we foster an interest and drive to participate in engineering from an early age. This discussion paper argues for the integration of engineering education within the elementary and middle school mathematics curricula. In doing so, we offer a definition of engineering education and address its core goals; consider some perceptions of engineering and engineering education held by teachers and students; and offer one approach to promoting engineering education within the elementary and middle school mathematics curriculum, namely through mathematical modeling.

INTRODUCTION

The world's demand for skilled workers in mathematics, science, engineering, and technology is increasing rapidly yet supply is declining across several nations, with the number of engineers graduating from U.S. institutions slipping 20 percent in recent years (National Academy of Sciences, 2007; OECD, 2006). To complicate matters, recent data reveal waning student interest in engineering, poor educational preparedness, a lack of diverse representation, and low persistence of current and future engineering students (Dawes & Rasmussen, 2007; Lambert, Diefes-Dux, Beck, Duncan, Oware, & Nemeth, 2007). We need young scholars to be involved in the next generation of innovative ideas that support our society's needs. This interest and drive to participate in engineering must be fostered from an early age. To date, there has been very limited research on integrating engineering experiences in the elementary and middle school curricula.

The field of engineering education is just emerging, with a number of questions identified for attention. These include: "What constitutes engineering thinking for elementary/middle school children?", "How can the nature of engineering and engineering practice be made visible to young learners?", "How can we integrate engineering experiences within existing school curricula?", "What engineering contexts are meaningful, engaging, and inspiring to young learners?", and "What teacher professional development opportunities and supports are needed to facilitate teaching engineering thinking within the curriculum?" (Cunningham & Hester, 2007; Dawes & Ramussen, 2007; Kuehner & Mauch, 2006; Lambert et al., 2007).

This paper begins a discussion on some of the above issues. In particular, we offer a definition of engineering education and address its core goals; we consider some perceptions of engineering and engineering education held by teachers and students; and we offer one approach to promoting engineering education within the elementary/middle school mathematics curriculum.

WHAT IS ENGINEERING EDUCATION?

The field of engineering has been described in many ways. Wulf (1998) referred to engineering as "design under constraint. Engineering is synthetic - it is creating, designing what can be, but it is constrained by nature, by cost, by concerns of safety, reliability, environmental impact, and many other...” (p.1). Given the urgent need for more engineers in diverse fields, it is timely to address the introduction of engineering-based experiences (engineering education) within the elementary and middle school curricula.

Engineering education in the elementary/middle school is a significant, nascent field of research that aims to foster children's appreciation and understanding of what engineers do and how engineering shapes the world around them. Engineering-based experiences encourage students to generate effective tools for dealing with our increasingly complex, dynamic, and powerful systems of information (Zawojewski, Hjalmarson, Bowman, & Lesh, 2008). The experiences build on children's curiosity about the scientific world, how it functions, and how we interact with the environment, as well as on children's intrinsic interest in designing, building, and dismantling objects in learning how they work (Petroski, 2003). Integrating engineering experiences within the elementary/middle school curricula also can help children appreciate how their learning in these domains can apply to the solution of real-world problems.

One of the foremost institutions that are introducing engineering into the elementary mathematics and science curricula is the National Center for Technological Literacy at the Museum of Science in Boston (Cunningham & Hester, 2007). The goals and activities of their *Engineering is Elementary* program are well suited for integration within the school curricula and provide fertile ground for interdisciplinary research. Cunningham and Hester (2007) have identified three core goals of their *Engineering is Elementary* program, namely, to: (a) Increase children's technological literacy; (b) Increase elementary educators’ abilities to teach engineering and technology to their students; and (c) Modify systems of education to include engineering at the elementary level.

With respect to the first goal, it is important that children develop: a knowledge of what technology and engineering in its various forms entail and what engineers do; an appreciation of how engineering and technology have shaped so many facets of our world, and how society influences and is influenced by engineering and technology; and an understanding and appreciation of how mathematics and science are applied to solving engineering problems, of which there are multiple solutions. A facility in applying an engineering design process in solving real-world problems is also an important component of this first goal, as we address in a later section.

With respect to the second goal, for teachers to be able to effectively integrate engineering experiences within the primary mathematics and science curricula, they need professional development and appropriate resources to scaffold their understanding and pedagogical strategies. As we indicate next, the vast majority of elementary school teachers have had little or no education about engineering concepts or ways of implementing engineering experiences within the curriculum.

The third goal listed above requires targeting state education systems to provide opportunities for engineering experiences in the elementary school. Some nations are beginning to address this issue. For example, the INSPIRE (Institute for P-12 Engineering Research and Learning) team at Purdue University is initiating and leading an advocacy effort at state and national levels to inform and influence policy-making that will increase the U.S. commitment to P-12 engineering education. In instigating these broad-scale efforts, it is imperative that teachers' and students' perceptions of engineers and engineering be addressed (Lambert et al., 2007).

PERCEPTIONS OF ENGINEERING AND ENGINEERING EDUCATION

As our society becomes increasingly dependent on engineering in its various forms, it is more important than ever that citizens have a basic understanding of what engineering entails, of what engineers do, and of the uses and implications of the technologies that they generate (Cunningham & Hester, 2007; Knight & Cunningham, 2004). However, few studies have probed students' and teachers' understanding of these issues. The little research that has been conducted has indicated that people generally do not understand what engineers do, despite being surrounded by the products of engineering in their everyday world (e.g., Cunningham, Lachapelle, & Lindgren-Streicher, 2005; Davis & Gibbon, 2002; Knight & Cunningham, 2004; Lambert et al., 2007). For example, Cunningham et al. (2005) found that school teachers are more likely to believe that engineers build rather than supervise the construction of buildings.

Little appreciation of the role of mathematics, science, and technology in engineering was noted by Lambert et al. (2007) in their study of P-6 teachers' perceptions and understanding of engineering. Furthermore, few teachers offered ideas about the need for team work, communication, and global/societal perspectives in engineering. Nor did the teachers identify engineering as creative but bounded by constraints.

Teachers' limited views on accessibility to engineering courses was noted by Douglas, Iversen, and Kalyandurg (2004). Their study indicated that teachers generally believe that engineering has a major impact on their daily lives and that implementing engineering concepts within the curriculum is certainly warranted. However, there is the belief that engineering is not an option for a large number of students and that the field is very difficult to enter at the university level.

Findings from the scant studies that have explored school students' conceptions of engineering indicate that students generally do not understand what engineers do. For example, Cunningham et al. (2005) administered their *What is an Engineer?* instrument to over 6000 elementary school students and found that they strongly conflate construction workers and auto mechanics with engineers. This is perhaps not surprising, given that these fields are not traditionally populated by women, suggesting that such narrow views of engineering might be one reason for the lower number of females who enter engineering courses. It is imperative that we help our students and teachers understand the range and type of work that engineers do and appreciate the role of engineering in advancing society.

PROMOTING ENGINEERING EDUCATION WITHIN THE ELEMENTARY MATHEMATICS CURRICULUM

Engineering-based problem experiences readily align themselves with those of the mathematics (and science) curriculum. For example, engaging children in hands-on, real-world engineering experiences involves them in design process cycles that utilize powerful mathematical problem solving and reasoning processes. Many such design process cycles exist. The *Engineering is Elementary* program (Cunningham & Hester, 2007) emphasizes a process cycle involving the components: ask, imagine, plan, create, and improve (see Fig. 1). The design process can begin at any component, with movement back and forth between the components occurring numerous times.

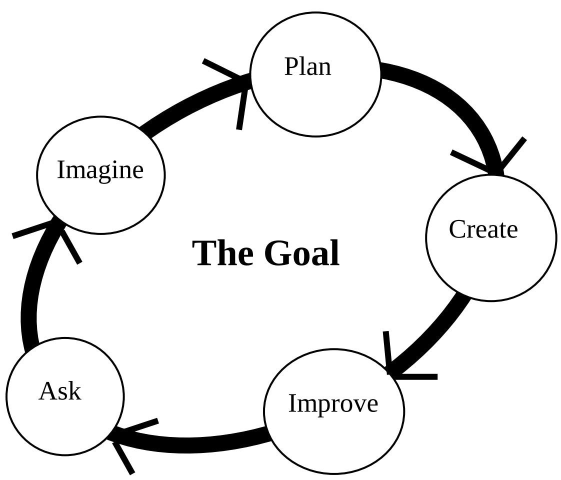

Figure 1: A cyclic process of engineering design.

We address here one means to designing and implementing engineering experiences within the mathematics curriculum, one that utilizes a comprehensive variation of the above design process cycle, namely, a models and modeling approach (Diefes-Dux & Duncan, 2007; English, 2007, in press; Lesh & Doerr, 2003). In adopting this approach, we present real-world engineering situations in which children 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. Diefes-Dux, Osburn, Capoobianco, and Wood (2008) describe the development of such models in terms of four key, iterative activities, which they represent in a flow diagram shown in Figure 2:

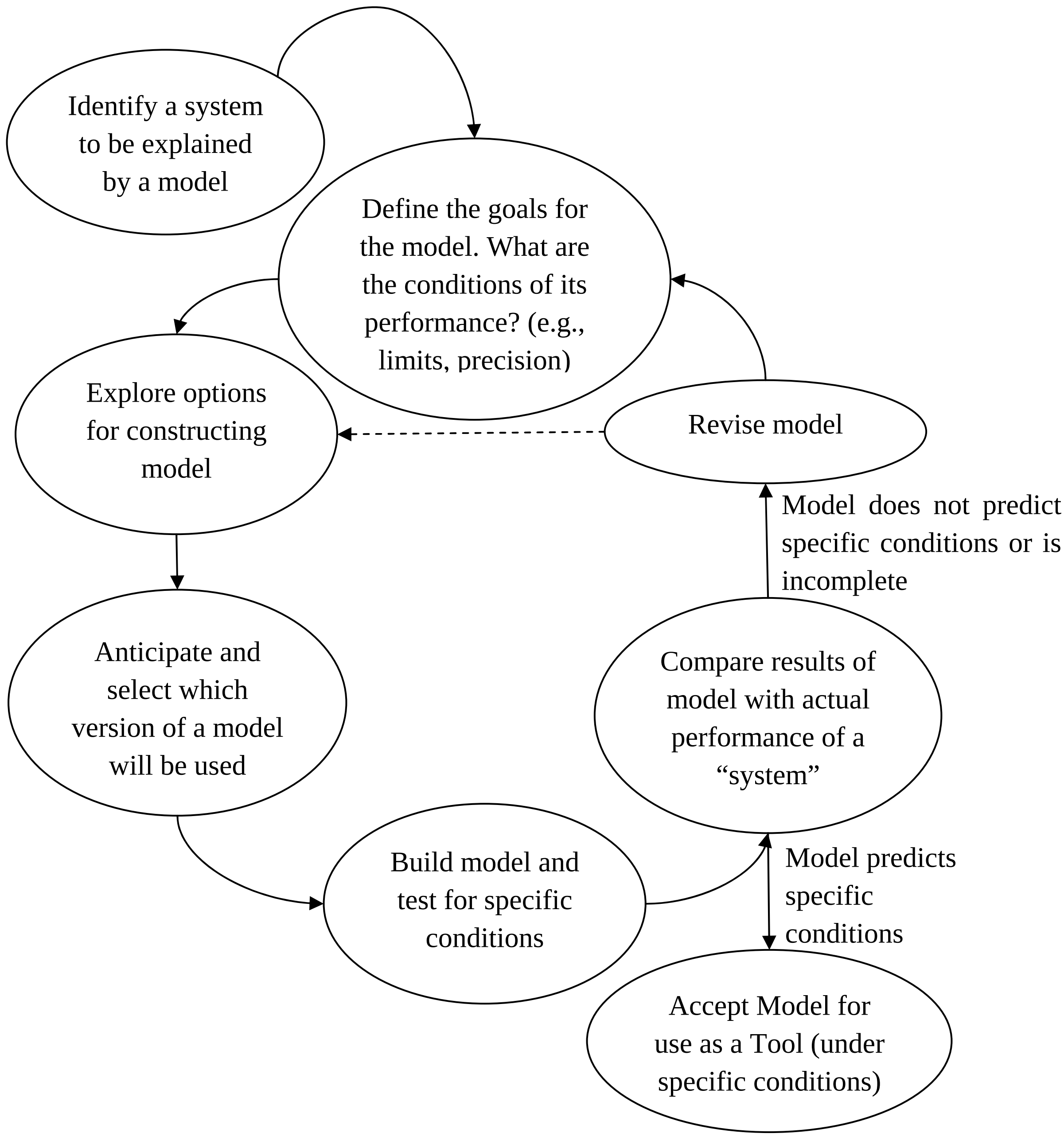

Figure 2: Model Development Process.

1. Understanding the context of the problem and the system to be modeled;
2. Expressing/testing/revising a working model;
3. Evaluating the model under conditions of its intended application; and
4. Documenting the model throughout the development process.

Students engage in these iterative activities when they undertake model-eliciting engineering-based problems, which we address next.

Model-Eliciting Engineering-Based Problems

The engineering-based problems we have implemented in elementary and middle-school classrooms are realistic open-ended problems where a client requires a team of workers to generate a product (a model) for solving the given problem. The model identifies a *process* that the client can use to solve the problem. We provide an example here of an environmental engineering problem, namely, the *Water Shortage Problem* (Mousoulides, 2008; we present part of the problem in the appendix; space prevents the entire problem being included but this can be obtained from the authors).

In the *Water Shortage Problem* students are sent a letter from a client, the Ministry of Transportation, who needs a means of (model for) selecting a country that can supply Cyprus with water during the next summer period. The letter asks students to develop a procedure/model using the data provided from three countries and also to obtain extra data, using available tools such as Google Earth, maps, and the Web. The quantitative and qualitative data provided for each country include water supply per week, water price, tanker capacity, and ports' facilities. Students can also obtain data about distance between countries, major ports in each country, and oil consumption. After students have developed their model, they write a letter to the client detailing how their model selects the best country for supplying water. Upon completion of their letter, students receive a second letter from the client including data for two more countries; students are asked to test their model on the expanded data and improve their model, if needed.

Engineering problems such as the *Water Shortage Problem* are designed to be thought revealing. The development of engineering problems is guided by six principles for designing model eliciting activities (Diefes-Dux, Hjalmarson, Miller, & Lesh, 2008). A brief description of the principles and how these have been applied in the design of the Water Shortage Problem are presented below.

According to the *Model Construction Principle,* the design of the problem requires the creation of a model by the student team; the model is often a procedure for carrying out a task. The Water Shortage Problem requires students to develop a procedure for selecting the best among different countries that can supply Cyprus with water, taking into consideration both qualitative and quantitative data as well as other necessary data students should obtain.

The Water Shortage Problem is inline with the *Reality Principle*, which requires the problem to be situated in an authentic engineering context. The Water Shortage Problem is an authentic environmental engineering problem that is also of great interest for the majority of students. According to the third principle, the *Self-Assessment Principle,* the design of the problem provides opportunities for students to work in their teams to assess the appropriateness of their models for selecting the best country. The problem also requires students to produce a documentation of their model (writing a letter to the Ministry of Transportation), which meets the *Model Documentation Principle* requirement. The problem also takes into account the *Model Shareability and Reusability* and *Effective Prototype Principles*—the models that students develop should be applicable to structurally similar engineering problems.

Engineering problems that meet the above principles, such as the *Water Shortage Problem*, are designed so that multiple solutions of varying mathematical sophistication are possible and children with a range of personal experiences and knowledge can tackle them. The products children create are documented, shareable, reusable, and modifiable mathematical models that provide teachers with a window into their students' conceptual strengths and weaknesses.

Another important feature of these problems is the opportunities provided for multiple feedback points to encourage children to rethink their models (e.g., through "what-if" questioning) and for discussion on the strengths and weaknesses of their models (with respect to the client's criteria for success) across a classroom full of alternative models. Furthermore, these modeling problems build communication (oral and written) and team-work skills, both of which are essential to success in mathematics and engineering.

CONCLUDING POINTS

We have argued here for the integration of engineering education within the elementary and middle school mathematics curriculum and have offered one approach to achieving this through mathematical modeling. Engineering-based modeling experiences provide opportunities for students to deal with multidisciplinary contexts, to identify, formulate, and solve real-world engineering problems, and to communicate their ideas effectively to others. Engineering education for younger students is a new and much-needed field of research. The elementary/middle school curriculum provides ideal opportunities for introducing children to foundational engineering ideas and principles. We consider it imperative that young scholars develop a strong curiosity and drive to learn how engineering shapes their world and supports so many of our society's needs.

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APPENDIX

Water Shortage Problem: Cyprus will buy Water from Nearby Countries

Background Information: One of the biggest problems that Cyprus faces nowadays is the water shortage problem. Instead of constructing new desalination plants, local authorities decided to use oil tankers for importing water from other countries. Lebanon, Greece and Egypt expressed their willingness to supply Cyprus with water. Local authorities have received information about the water price, how much water they can supply Cyprus with during summer, tanker oil cost and the port facilities.

Problem: The local authorities need to decide from which country Cyprus will import water for the next summer period. Using the information provided, assist the local authorities in making the best possible choice. Write a letter explaining the method you used to make your decision so that they can use your method for selecting the best available option (The following **table** was supplied).

Country	Water Supply per week (metric tons)	Water Price (metric ton)	Tanker Capacity	Oil cost per 100 km	Port Facilities for Tankers
Egypt	3 000 000	€ 3,5	30 000	€ 20000	Good
Greece	4 000 000	€ 2	50 000	€ 25000	Very Good
Lebanon	2 000 000	€ 4	50 000	€ 25000	Average