# Providing Engineering Experiences to Elementary School Students

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## Abstract

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 paper argues for the integration of engineering education within the elementary school mathematics and science curricula. In doing so, we address engineering education's core goals for elementary school students and present one approach to promoting engineering education within the elementary school mathematics and science curriculum, namely through mathematical modeling. In this study we report on an analysis of the mathematical developments of twenty two 12 year old students as they worked on a complex environmental modeling problem. The activity required students to analyse a real-world situation based on the water shortage problem in Cyprus, to pose and test conjectures, to compare alternatives, and to construct models that are generalizable and re-usable. Results provide evidence that students successfully constructed models for solving the problem, considering a number of environmental and energy consumption related concerns. Students' mathematical developments included creating models for selecting the best place to supply Cyprus with water, finding and relating variant and invariant measures such as tanker capacity, oil consumption, and water price. Finally, implications for further research are discussed.

## Introduction

The need for young scholars that will study engineering at the university level and be involved in the next generation of innovative ideas that support our society's needs is nowadays greater than ever. The world's demand for skills in mathematics, science, engineering, and technology is increasing rapidly yet supply is declining across several nations (National Academy of Sciences, 2007). Recent studies 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).

Engineering education for elementary school students is a new, yet increasingly important to the various fields of engineering and represents a new domain of research by mathematics, science, and engineering educators. Among the core questions that are posed in related research are the following: "What constitutes engineering thinking for elementary 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 & Rasmussen, 2007).

This paper begins a discussion on engineering education for young learners by addressing engineering education's goals for elementary school students. In particular, the paper presents an example of the integration of engineering education on elementary school mathematics and science curriculum, by discussing one approach to promoting engineering education within the elementary mathematics curriculum, namely through Engineering Model Eliciting Activities (EngMEA).

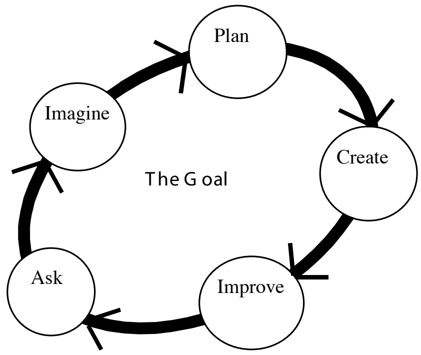
## Engineering Education for Young Learners

Among engineering education's aims in the elementary and secondary school is the understanding and appreciation of the problems engineers face, how engineering shapes the world utilizing important ideas from mathematics and science, and how it contextualizes mathematics and science principles (Dawes & Rasmussen, 2007). Engineering education builds on young learners' curiosity about the natural world, how it functions, and how people interact with the environment, as well as on students' intrinsic interest in designing, building, and dismantling objects in learning how they work (Petroski, 2003).

The integration of engineering education within the school mathematics and science curricula is important for a number of reasons. Appropriate engineering experiences within the elementary school curricula can: (a) help students appreciate how their learning in mathematics and science can apply to the solution of important real-world based engineering problems, (b) lead to better preparedness of senior subjects, (c) highlight the relevance of studying mathematics and physical sciences, and (d) help students appreciate the usefulness of the various fields of engineering and the role of the engineer in the society (Zawojewski, Hjalmarson, Bowman, & Lesh, 2008; Diefes-Dux et al., 2008). Students learn how to apply the engineering design process in solving real-world problems; they learn to think creatively, critically, flexibly, and visually, and to troubleshoot and learn from failure. From the teacher perspective, considering that the majority of them has no education about engineering concepts and thinking, there is a strong need to provide professional development and appropriate resources to scaffold their understanding and pedagogical strategies to be able to effectively integrate engineering experiences within the elementary mathematics and science curricula (Zawojewski et al., 2008).

Engineering-based problem experiences engage students in design process cycles that utilize powerful problem solving and reasoning processes. A design process proposed by Cunningham and Hester (2007), involves the components: ask, imagine, plan, create, and improve (see Figure 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 and science curriculum, one that utilizes a comprehensive variation of the above design process cycle, namely, a models and modeling approach (Zawojewski, Hjalmarson, Bowman, & Lesh, 2008; Lesh & Doerr, 2003). In EngMEAs students 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, 2007; Mousoulides, Sriraman & Lesh, 2008). Diefes-Dux, Osburn, Capoobianco, and Wood (2008) describe the development of such models in terms of four key, iterative activities, namely: (a) Understanding the context of the problem and the system to be modelled, (b) Expressing / testing / revising a working model, (c) Evaluating the model under conditions of its intended application, and (d) Documenting the model throughout the development process. These key iterative activities can be traced in the implementation of the engineering modeling activity discussed in the present paper under Results session.

## A Models and Modeling perspective in Engineering Education

A means of integrating engineering education within the elementary mathematics and science curriculum is through the models and modeling perspective (Lesh & Zawojewski, 2007). The models and modeling perspective complements and enriches the engineering design process. According to the modeling perspective, the components of a basic engineering design process are: Ask (What is the problem? What have others done? What are the constraints?), Imagine (What are some possible solutions?), Plan (e.g., what diagram/sketch can you draw? Make a list of materials needed.), Create (Follow your plan and create it; test it out), and Improve (Discuss what works, what doesn't, and what could work better; modify your design to make it better; test it out.) (Cunningham & Hester, 2007). Using the models and modeling perspective, students have opportunities to create, apply and adopt mathematical and scientific models in interpreting, explaining and predicting the behavior of real-world based engineering problems.

In adopting the models and modeling approach, real-world engineering situations are presented to students. These Engineering Model Eliciting Activities (EngMEAs), offer students opportunities to repeatedly express, test, and refine or revise their current ways of thinking as they endeavor to create a structurally significant product—structural in the sense of generating powerful mathematical and engineering constructs. In EngMEAs students undergo a cyclic process of interpreting the problem information, selecting relevant quantities, identifying operations that may lead to new quantities, and creating meaningful representations (Lesh & Doerr, 2003). These cyclic processes of modeling and engineering design are very similar: a problem situation is interpreted; initial ideas (initial models, designs) for solving the problem are called on; a fruitful idea is selected and expressed in a testable form; the idea is tested and resultant information is analysed and used to revise (or reject) the idea; the revised (or a new) idea is expressed in testable form; etc. The cyclic process is repeated until the idea (model or design) meets the constraints specified by the problem (Zawojewski et al., 2008).

In sum, from a models and modeling perspective, these engineering-based activities are realistically complex problems where the students engage in mathematical and scientific thinking beyond the usual school experience and where the products to be generated often include complex artifacts or conceptual tools that are needed for some purpose, or to accomplish some goal (Lesh & Zawojewski, 2007). EngMEAs present a future-oriented approach to learning, where students are given opportunities to elicit their own mathematical and scientific ideas as they interpret the problem and work towards its solution (Mousoulides et al., 2008).

## The Present Study

### Participants and Procedures

One class of 22 twelve year olds and their teacher worked on an environmental engineering modeling problem as part of a longitudinal study, which focuses on exploring students' development of models and processes in working with modeling problems. The students are from a public K-6 elementary school in the urban area of a major city in Cyprus. The students only met such modeling problems during their participation in the current project, as the mathematics curriculum in Cyprus rarely includes any modeling activities.

The data reported here are drawn from the problem activities the students completed during the first year of the project. The Water Shortage modeling problem entails: (a) A warm-up task comprising a newspaper article, designed to familiarize the students with the context of the modeling activity. The article discussed the water shortage problem in a number of countries and presents a number of possible solutions. (b) "Readiness" questions to be answered about the article, and (c) The problem to be solved, including the tables of data (see Table 1).

The environmental modeling activity provided background information on Water Shortage problem, one of the biggest problems Cyprus face today. Students were informed on government's decision to use oil tankers for importing water from other countries instead of constructing new desalination plants. 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 period, tanker oil cost, and the port facilities. Students were asked to use the information provided in developing a model for ranking the three countries, in order to help local authorities making the best possible choice. Students also had to write a letter to the local authorities, explaining the method they used to make their decision, and documenting their model.

Table 1: The Water Shortage Problem Data

| Country | Water Supply per week (metric tons) | Water Price (metric ton) | Tanker Capacity (metric tons) | Tanker Oil cost per 100 km | Port Facilities for Tankers |
|---|---|---|---|---|---|
| Egypt | 3 000 000 | € 3.50 | 30 000 | € 20 000 | Good |
| Greece | 4 000 000 | € 2.00 | 50 000 | € 25 000 | Very Good |
| Lebanon | 2 000 000 | € 4.00 | 50 000 | € 25 000 | Average |

The problem was implemented by the authors and the classroom teacher. Working in groups of three to four, the children spent four 40-minute sessions on the activity. During the first two sessions the children worked on the newspaper article and the readiness questions and familiarized themselves with the available software (Google Earth and spreadsheets). In contrast to regular maps, Google Earth can help students in making accurate calculations, being more precise in drawing the tanker routes, in "visiting" the different countries for exploring their major ports and finally in observing country's landscape. In the next two sessions students developed their models and wrote letters to local authorities, explaining and documenting their models/solutions. Documenting their results/models in the letters to the local authorities is an important aspect not only of the activity, but also of the engineering profession, since an important aspect of the engineering profession is the ability to effectively communicate the results of their work.

### Data Sources and Analysis

The data sources were collected through audio- and video-tapes of the students' responses to the modeling activity, together with the Google Earth and spreadsheet files, student worksheets and researchers' field notes. Data were analysed using interpretative techniques (Miles & Huberman, 1994) to identify developments in the model creations with respect to the ways in which the students: (a) interpreted and understood the problem, (b) used and interacted with the software capabilities and features in solving the environmental problem, and (c) selected and categorized the data sets, used digital maps and applied mathematical operations in transforming data. In the next section we summarize the model creations of the student groups in solving the Water Shortage activity.

## Results

### Group A Model Creations

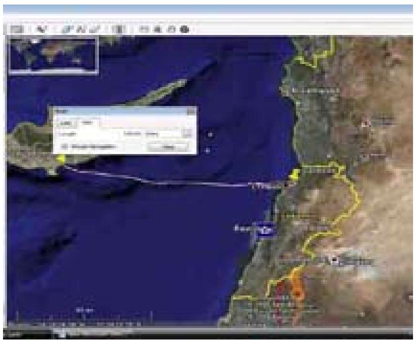
Group A started their exploration by "visiting Lebanon", a nearby country, using the "Fly to" command. This approach helped students in identifying that there were many mountains and therefore Lebanon could supply Cyprus with water. In their final report, students documented that: "Lebanon has a high percentage of precipitation, because there are many mountains there. So, they will probably sell water to Cyprus". By "zooming in" they easily found a major port (Tripoli) and they added a Placemark there. Students then "zoom out", moved to Cyprus and added a second placemark in Limassol, Cyprus major port. Group A then used the "ruler" feature of the software for calculating the distance between Tripoli and Limassol.

Students followed the same approach for placing placemarks in Pireus (in Greece) and Cairo (Egypt), and for finding the distances between Cyprus and the other two countries. Since the data table (see Table 1) was supplied in spreadsheet software, students added one column presenting the distances between the three different countries and Cyprus. Students explicitly discussed about oil price, and they reached the conclusion that buying water from Greece would be more expensive than buying water from Lebanon or Egypt due to the greater distance between Greece and Cyprus. Students, however, failed to successfully use the provided data and they finally based their choice (Lebanon) partly on the provided data and on their calculations, without providing a coherent model. Of interest is also the absence of any discussion between students about the environmental aspects of the problem; a dimension that was evident in other Groups' work.

**Group B Model Creations**

Similar to the work of Group A, students in this group quite easily visited the three countries and added placemarks in their major ports. They drew precise paths between each country's port and Limassol and used ruler to calculate the distances (see Figure 2).

Figure 2: Finding the distance between Tripoli and Limassol



They reported that: "It is not easy to decide from which country Cyprus should buy water. Lebanon for example is closer than Greece, but water from Greece is much cheaper than water from Lebanon. After calculating the distances between the countries using Google Earth, they moved into the spreadsheet software and added one column in the provided table, presenting the distances between countries' major ports. They, however, failed to incorporate into their model the provided data about oil cost, tanker capacity and water price.

**Group C Model Creations**

This group commenced the problem by finding a major port in each one of the three countries and by drawing paths from these ports to Limassol. Students in this group then calculated the distances between the ports and continued in calculating oil and water cost for each tanker trip. In contrast to Groups A and B, students in this group incorporated within their model one more factor; instead of calculating the total cost for each trip and then ranking the three countries, they decided to calculate the cost per water metric ton and based their ranking on this factor. As a result, this model ranked Lebanon as the best possible choice, since the average cost per water ton was only €4.20. On the contrary, the average costs for Egypt and Greece were €6.70 and €7.00 respectively. Student calculations and final selection are presented in Table 2.

Table 2: Group C calculations and final model

| **Country** | **Distance (km)** | **Oil cost** | **Water cost per tanker** | **Total cost** | **Average water cost per ton** |
|---|---|---|---|---|---|
| Egypt | 480 | € 96000 | € 105000 | € 201000 | € 6.70 |
| Greece | 1100 | € 275000 | € 75000 | € 350000 | € 7.00 |
| Lebanon | 240 | € 60000 | € 150000 | € 210000 | € 4.20 |

Although this group differed from other groups in that they used a more refined model, they also failed to apply in their model factors such as port facilities for tankers and each country's resources for supplying water to Cyprus. Students in this group, similar to group A and B did not use in their calculations round trips but they rather based their calculations on single trips.

**Group D Model Creations**

Similar to group's C work, students in group D students started the problem by performing the same calculations and reaching the same mathematical model. However, group's D work was different from Group's C work in a number of dimensions. Students in this group extensively discussed a number of factors, like tanker capacity and port facilities. They reported that improving port facilities in Lebanon, for example, will cost money that needs to be considered in calculating the cost per water ton. In their letters, students reported that more data was needed in order to develop a more coherent model.

A second dimension that was of interest in this group's work was the discussion about tanker capacity and oil cost. Students were aware of energy consumption issues and they discussed in their group that oil consumption should be kept as minimum as possible. When their teacher prompted them to decide which factor is more important, water price or oil consumption, students replied that it would be better for the country to spend a little more money and to reduce oil consumption. They also made explicit that it was not only oil consumption but also other environmental issues, like the pollution of the Mediterranean sea.

### Remaining Groups' Model Creations

Students in the remaining three groups faced a number of difficulties in ranking the different countries. In the first component of the problem, using Google Earth for finding appropriate ports and calculating the distances between Cyprus and the three countries, two groups focused their efforts only on Greece, by finding the distance between Pireus and Limassol. Some other groups faced a number of difficulties in using the software itself.

In the second component of the problem, transferring the distance measurements in the spreadsheet software and calculating the different costs, the students faced more difficulties. Most of their approaches to problem solution were not successful. Many students, for example, just made random calculations, using partially the provided data, and finally making a number of data misinterpretations. One group, for example reported that buying water from Greece is the best solution, since the water price per ton from Greece was only €2.00 (see Table 1).

## Concluding Points

We have argued here for the integration of engineering education within the elementary mathematics and science curriculum and have suggested one approach to achieving this goal, through the models and modeling perspective. EngMEAs provide opportunities for students to deal with complex engineering contexts, to identify, formulate, and solve real-world engineering problems. Engineering education at the elementary school level can provide opportunities for students to explore fundamental engineering ideas and principles and furthermore to assist students in further developing their problem solving skills.

There are a number of aspects of this study that have particular significance for the use of EngMEAs in elementary school curricula. First, although a number of students in the present study experienced difficulties in solving the problem, elementary school students can successfully participate and satisfactorily solve complex environmental modeling problems when presented as meaningful, real-world case studies. Second, our findings show that the available software broadened students' explorations and visualization skills through the process of constructing visual images to analyze the problem, and by using appropriately the spreadsheet's formulas they performed quite complex calculations.

The students' models varied in the number of problem factors they took into consideration. Interestingly, at least three groups succeeded in identifying dependent and independent variables for inclusion in an algebraic model and in representing elements mathematically so formulae can be applied. A number of groups of students made the relevant assumptions for simplifying the problem and ranking the three countries. Further, at least one group of students explicitly discussed a number of related environmental concerns related to the problem and tried to incorporate these concerns in their final models.

The findings of the present study are also of interest for a number of reasons related to the design and implementation of engineering modeling activities for young students. First, especially when students have no prior experience in working with modeling activities, students need to be encouraged to integrate all available information and even look for more resources and information. Second, students need to be aware that it is useful and necessary to be able to simplify engineering problems in order to arrive at some initial solutions, which may be refined further at a later stage as needed, using more data. Further, in contrast to traditional problem solving activities, in modeling activities students often need to quantify information, combine qualitative and quantitative information, and apply decision making approaches (Mousoulides et al., 2008). Decision making is not a straightforward process; students need to appreciate through such modeling activities that in engineering problems it is necessary to combine many factors some of which may be conflicting, there may be multiple objectives that need to be satisfied, and there is not always a unique solution, as highlighted by the last groups' work.

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. Practice in such engineering problems assist the development of elementary school students' engineering thinking and improve students' ability to deal with complex multi-disciplinary contexts. Engineering education for younger students is a new and much-needed field of research. The elementary school curriculum provides ideal opportunities for introducing students 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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