Integrating Engineering Experiences within the Elementary Mathematics Curriculum

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Abstract*: Engineering education for elementary school students is a new and increasingly important domain of research by mathematics, science, technology, and engineering educators. Recent research has raised questions about the context of engineering problems that are meaningful, engaging, and inspiring for young students. In the present study an environmental engineering activity was implemented in two classes of 11-year-old students in Cyprus. The problem required students to use the data to develop a procedure for selecting among alternative countries from which to buy water. Students created a range of models that adequately solved the problem although not all models took into account all of the data provided. The models varied in the number of problem factors taken into consideration and also in the different approaches adopted in dealing with the problem factors. At least two groups of students integrated into their models the environmental aspect of the problem (energy consumption, water pollution) and further refined their models. Results provide evidence that engineering model-eliciting activities can be successfully integrated in the elementary mathematics curriculum. These activities provide rich opportunities for students to deal with engineering contexts and to apply their learning in mathematics and science to solving real-world engineering problems.*

Engineering Education for Young Learners

Engineering education at the primary and secondary school levels aims to help students understand and appreciate 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). 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?", and “How can we integrate engineering experiences within existing school curricula?” (Cunningham & Hester, 2007; Dawes & Rasmussen, 2007). In this paper we present an example of the integration of engineering education within the elementary school mathematics and science curricula, namely, through the use of Engineering Model Eliciting Activities (EngMEAs).

Such integration is important for a number of reasons. Appropriate engineering experiences within the elementary 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, Diefes-Dux, & Bowman, 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 they learn to troubleshoot and gain from failure.

A Models and Modeling perspective in Engineering Education

One means of integrating engineering education within the elementary mathematics and science curriculum is through a *models and modeling perspective* (Lesh & Zawojewski, 2007). This perspective complements and enriches the engineering design process. One basic engineering design process involves the cyclic processes of: *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). The models and modelling perspective utilizes a comprehensive variation of the above design process cycle. Students are presented with real-world engineering situations (Engineering Model-Eliciting Activities [EngMEAs]) 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, Sriraman & Lesh, 2008). Through a 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.

Lesh and Zawojewski (2007) 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. The cyclic process is repeated until the idea (model or design) meets the constraints specified by the problem (Zawojewski et al., 2008).

The Present Study

Participants and Procedures

Two classes of 38 eleven year olds and their teachers worked on an environmental engineering modeling problem as part of a longitudinal 3 year study, which focuses on enhancing students' awareness of basic engineering concepts and processes (e.g., decision making) and on exploring students' development of mathematical models. The students are from a public K-6 elementary school in the urban area of a major city in Cyprus. The data reported here are drawn from the problem activities the students completed during the first year of the project. Engineering and mathematical modeling problems of the present type were new to students, since current curricula do not include any modeling activities. However, students were familiar with working in groups and communicating their mathematical ideas to their peers.

The *Water Supply* modeling activity entails: (a) A warm-up task comprising a newspaper article, designed to familiarize the students with the context of the modeling activity. The article focused on the water shortage problem a number of countries faced nowadays. The article further presented a discussion on the actions these countries take for solving the problem. (b) "Readiness" questions to be answered about the article, and (c) The problem to be solved, including the tables of data (see Table 1). Students were asked to use the information provided and any other resources they might find useful to develop a model for ranking the four countries, in order to help local authorities making the best possible choice. After completing the activity, students had to write a letter to the local authorities, documenting the method they used to develop 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	€ 4.00	30 000	€ 20 000	Average
Greece	4 000 000	€ 2.00	50 000	€ 25 000	Very Good
Lebanon	2 000 000	€ 5.20	30 000	€ 20 000	Average
Syria	3 000 000	€ 5.00	30 000	€ 20 000	Good

The problem was implemented by the first author, a postgraduate student, and the classroom teachers. Working in mixed-ability groups of three to four, students spent four 40-minute sessions on the activity. During the first session the students worked on the newspaper article and the readiness questions. In the next three sessions students developed their models and wrote letters to local authorities, explaining and documenting their models/solutions. To facilitate student explorations during the development of their models, Google Earth and spreadsheet software were available to them.

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) selected and categorized the data sets, used digital maps and applied mathematical operations in transforming and merging data, and (c) integrated the environmental aspects of the engineering problem. Eight out of the eleven groups of students worked on the modeling activity succeeded in developing appropriate models for solving the problem. These solutions are summarized in the four different models presented in the next section.

Results

Model A

Four groups developed quite similar models for solving the *Water Supply* problem. These groups used Google Earth's capabilities for "visiting" the four countries and finding their major ports. Students then calculated distance between Cyprus and these countries and added new data in the provided data table. Students then calculated the water cost for each country and ranked the four countries. All four groups selected Greece to supply Cyprus with water, since water from Greece would cost less than water from other three countries. One group's work is presented in detail in the following paragraphs.

Students started their explorations by using the "Fly to" command to visit Lebanon. Their first discussions focused on Lebanon's landscape; they observed that there were many mountains and therefore Lebanon could supply Cyprus with water. Students then explored Lebanon's coast and decided that Tripoli was a major port. They finally added a placemark in Tripoli. Students then "zoom out", moved to Cyprus and added a second placemark in Limassol, Cyprus major port. The group used the software's "Ruler" feature to calculate the distance between Tripoli and Limassol and added the data into their table.

Students followed the same approach for placing placemarks in Pireus (Greece), Latakia (Syria), and Cairo (Egypt). They continued calculating the distances between Cyprus and the other three countries and added new data in the provided table. Of interest was their decision to exclude some of the provided data (water supply per week and port facilities), which they finally did not include in developing their final model. The new data table is presented in Table 2. Using the data presented in Table 2, students developed a model for calculating total oil cost (multiplying Oil cost per 100 km by distance and dividing by 100), water cost per tanker (multiplying Water price by tanker capacity), total cost per trip (oil cost and water cost) and finally the water price per ton (see Table 3). This group (similar to other three groups) decided that buying water from Greece is the best possible solution. Overall, mathematical developments were significant in all four groups' work; however, students did not attempt to integrate in their models qualitative data (port facilities) or water supply per week data. Of interest is also the absence of any discussion between students about the environmental aspects of the problem.

Model B

Similar to the Model A, two groups followed the same approach, using the factors presented in model A. Students in these groups also found the major ports in each country and draw tanker routes (see Figure 1). What was different in these groups' work was their correct and more precise decision to base their calculations on round trips. As a result, their final ranking was different than the one presented in Model 1. Their final model is presented in Table 4. As a consequence, the groups reached a different solution; in their final letters they proposed to local authorities to buy water from Lebanon, since this was the cheapest choice.

Table 2: Model A New Data

Country	Water Price (metric ton)	Tanker Capacity (metric tons)	Tanker Oil cost per 100 km	Distance
Egypt	€ 4.00	30 000	€ 20 000	420
Greece	€ 2.00	50 000	€ 25 000	940
Lebanon	€ 5.20	30 000	€ 20 000	260
Syria	€ 5.00	30 000	€ 20 000	280

Table 3: Group's Final Model

Country	Distance (km)	Oil cost	Water cost per tanker	Total cost	Average water cost per ton
Egypt	420	€ 84000	€ 120000	€ 204000	€ 6.80
Greece	940	€ 235000	€ 100000	€ 335000	€ 6.70
Lebanon	260	€ 52000	€ 156000	€ 208000	€ 6.94
Syria	280	€ 56000	€ 150000	€ 206000	€ 6.87

Figure 1: Drawing Tanker routes between Cyprus and the other countries.

Table 4: Group's Final Model

Country	Distance (km)	Oil cost	Water cost per tanker	Total cost	Average water cost per ton
Egypt	420	€ 168000	€ 120000	€ 288000	€ 9.60
Greece	940	€ 470000	€ 100000	€ 570000	€ 11.40
Lebanon	260	€ 104000	€ 156000	€ 260000	€ 8.66
Syria	280	€ 150000	€ 150000	€ 262000	€ 8.73

Model C

This model was based on the work presented in model A. One group of students followed the same approach and developed a model, like the one presented in Table 3. However, this group further discussed the various aspects of the problem and questioned the appropriateness of their model, which ranked Greece first.

Students in this group extensively discussed sea pollution. Based on the newspaper article they worked on during the first sessions of the modeling activity, one student of the group raised the question whether it would be wise to buy water from Greece. He mentioned that distance from Pireus to Limassol was more than three times greater than distance from Lebanon and Syria, and he proposed to buy water from Egypt or Syria, the second and third country in their ranking. He continued documenting that all countries in the Mediterranean Sea should be fully aware of sea pollution and therefore try to minimize ship oil consumption. Another student suggested to buy water from Syria, since water price is not that expensive (compared to price from Greece and Egypt). Students finally ranked countries in the following order: Syria, Egypt, Lebanon and Greece and decided to propose to the local authorities to buy water from Syria.

Model D

The most sophisticated model presented in this activity was developed by another group of students. Compared to the model presented in the previous paragraphs, more factors were integrated in this model. Specifically, students in this group tried to quantify port facilities factor and took into consideration water supply per week data. While students in this group reached a first model similar to the one presented in Table 3, they decided to integrate in their calculations port facilities. A discussion followed, focused on the amount of money necessary for improving ports' facilities and how this amount of money would change the water price per ton. Students asked their teacher and the researcher for more information about the amount of money necessary for improving port facilities in Syria, Lebanon and Egypt. Students were surprised when their teacher replied that improving port's facilities would cost between five to ten million euro. They were concerned that the amount was very big and considered this to have a negative impact on these three countries. Students, however, did not succeed to integrate the new data into their 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. Finally, this group resulted in proposing Syria as the best place to buy water from.

Remaining Groups' Model Creations

Students in the remaining 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 and/or making wrong calculations in the spreadsheet.

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. The majority of their approaches 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

There are a number of aspects of this study that have particular significance for the use of EngMEAs in elementary school curricula. 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. The students' models varied in the number of problem factors they took into consideration. Interestingly, many groups succeeded in identifying dependent and independent variables for inclusion in an algebraic model and in representing elements mathematically so formulae could be applied. Further, a number of groups of students integrated in their models other aspects of the real problem (e.g., energy consumption, sea pollution) and therefore improved their 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, students need to be encouraged to integrate all available information and even look for more resources and information, especially when they have no prior experience in working with modeling activities. 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, that there may be multiple objectives that need to be satisfied, and that there is not always a unique solution, as highlighted by the last groups' work.

In concluding, 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.

References

Cunningham, C. M., & Hester, K. (2007). Engineering is elementary: An engineering and technology curriculum for children. In *Proceedings of the 2007 American Society for Engineering Education Annual Conference & Exposition*. Honolulu, Hawaii: American Society for Engineering Education.

Dawes, L., & Rasmussen, G. (2007). Activity and engagement—keys in connecting engineering with secondary school students. *Australasian Journal of Engineering Education, 13*(1), 13-20.

English, L. D. (2008). Interdisciplinary Problem Solving: A Focus on Engineering Experiences. Paper presented at the *31st Annual Conference of the Mathematics Education Research Group of Australasia*, Brisbane, Australia.

Lesh, R., & Zawojewski, J. S. (2007). Problem solving and modeling. In F. Lester (Ed.). *Second Handbook of Research on Mathematics Teaching and Learning* (pp. 763-804). Greenwich, CT: IAP.

Mousoulides, N., Sriraman, B., & Lesh, R. (2008). The Philosophy and Practicality of Modeling Involving Complex Systems. *The Philosophy of Mathematics Education Journal, 23*, 134-157.

Miles, M. and Huberman, A. (1994). *Qualitative Data Analysis* (2nd Ed.). London: Sage Publications.

Zawojewski, J., Diefes-Dux, H. A., & Bowman, K. (2008). *Models and Modeling in Engineering Education: Designing Experiences for all Students.* Netherlands: Sense Publishers.

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