Engineering Based Modeling Activities for Enhancing Student Communication and Teamwork Skills

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Abstract - **This paper argues for a future-oriented, inclusion of engineering modeling activities in introductory engineering courses at the university level. Engineering model eliciting activities provide a rich source of meaningful engineering problem situations that capitalise on and extend students' existing mathematics and engineering learning and provide opportunities for enhancing student communication and teamwork skills. We give consideration here to engineering modeling activities as a means for providing freshmen students with opportunities to work with real world engineering problems even in introductory courses, to develop their communication and teamwork skills, to develop and revise powerful models and to document and present their solutions. The models developed by a class of 26 first year civil engineering students in solving the Natural Gas activity are presented here. Results showed that students, working in groups, created models that adequately solved the engineering problem, and developed their communication skills. Finally, recommendations for implementing engineering modeling activities and for further research are presented.**

Index Terms – Civil engineering, Communication skills, Model Eliciting Activities, Teamwork skills.

INTRODUCTION AND THEORETICAL FRAMEWORK

The National Research Council's Board of Engineering Education recommends ensuring "early exposure to engineering practice and a sense of the role of the engineer in society" [1]. While in a traditional engineering education setting, engineering students often do not gain any experiences in solving complex problems that require teams of students until the third or fourth year, current reforms in engineering education underline the importance of providing engineering students with opportunities to work on multi-disciplinary teams and to apply mathematics and science when solving engineering problems, from the beginning of their studies [2]. For these reasons, it is imperative that engineering educators consider methods for bringing advanced engineering content into foundational courses and provide opportunities for students to develop their communication and teamwork skills [3].

The National Academy of Engineering (2005) in the *Educating the Engineer of 2020: Adapting Engineering Education to the New Century* document provides engineering educators with direction to accomplish the mission raised above. The authors of the document propose that the growing need to look at engineering problems with a "systems perspective" drives the need to "pursue collaborations of multi-disciplinary teams of technical experts" (p. 10). The document further states that one of the important elements of engineering is the "engagement of the engineer and professional from different disciplines in team-based problem-solving processes" [4].

One manner of addressing the calls for reform in Engineering and the introduction of problem solving skills in engineering programs, along with integrating teamwork and engineering contexts in the first years of engineering programs, is through the use of Engineering Model-Eliciting Activities (EngMEAs) – realistic, client-driven problems based on the theoretical framework of models and modeling [5]. An EngMEA is a complex problem set in a realistic context with a client, characteristics that place EngMEAs in the authentic assessment category [5]. Solutions to EngMEAs are generalizable models which reveal the thought processes of the students. The models created include procedures for doing things and, more importantly, metaphors for seeing or interpreting things. The activities are such that student teams of three to four express their mathematical model, test it using sample data under the possible engineering constrains, and revise their procedure to meet the needs of their client [6].

The EngMEAs framework provides a means not only to deliver more openended engineering problems (engineering content) but also address multiple ABET criteria, especially those that are problematic to integrate in more traditional engineering courses. Especially, they address criterion 3 which requires that engineering graduates can meet standards such as an "ability to function on multi-disciplinary teams," an "ability to communicate effectively," and an "ability to identify, formulate, and solve engineering problems" [2]. In sum, from the EngMEAs perspective, engineering-based problems are realistically complex situations where the problem solver engages in mathematical and engineering thinking beyond the usual introductory courses experience and where the products to be generated often include complex artifacts or conceptual tools [6,7]. The problems 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 [8].

Following NRC Board of Engineering Education recommendations for ensuring "early exposure to engineering practice and a sense of the role of the engineer in society" (1995), we have introduced a sequence of Engineering Model Eliciting Activities (EngMEAs) in an introductory course on Integrated Design for civil engineering students. In the present study, students worked on an engineering modeling activity related to natural gas consumption and reserves, as a part of a sequence of four engineering modeling activities. Student models and results in solving the *Natural Gas Modeling Activity* are presented in this study.

THE PRESENT STUDY

In this section we report on first year civil engineering students' models and solutions to an engineering modeling problem. The problem focuses on the natural gas resources and consumption. The activity presented data related to the worldwide reserves of natural gas in 1993 and the annual average consumption for the next 15 years. Specifically, the activity provided students with the following information:

"In 1993 the worldwide reserves of natural gas were estimated to be 141.8 billion cubic metres. Since then 2.5 billion cubic metres have been used every year on average. Calculate when the reserves of natural gas will be exhausted"

The activity required students to use different assumptions and develop model(s) for calculating when the reserves of natural gas will be exhausted. In implementing the activity, we were primarily interested in: (a) how the students interpreted the problem, (b) the ways in which the students worked with the provided data and the extra data they retrieved from the Web, and (c) the nature of the models the students generated in solving the problem.

One class of 26 first year civil engineering students worked on the problem as part of one introductory course on Integrated Design. Since this problem was part of a sequence of four modeling activities, students were familiar with working in groups, developing models for solving quite complex problems, and presenting and documenting their results. The problem was implemented by the author and one postgraduate student. Students, randomly assigned to groups of three to four, spent sixty minutes on the problem. During the sixty minutes students searched the Web for finding useful data, and then developed and documented their models.

Our data sources included audio- and video-tapes of the students' responses to the problem, together with their worksheets and the researchers' field notes. Specifically, the researchers videotaped the whole class discussions, and audiotaped each group of students. Using interpretative techniques [9], the transcripts were reviewed by the researchers to identify and trace developments in the model creations of the students with respect to: (a) the ways in which the students interpreted and understood the problem, (b) their initial approaches to dealing with the data sets, and (c) the ways in which they selected data sets, and applied mathematical operations. In the next section we summarize the model creations of the student groups in solving the *Natural Gas* activity.

RESULTS

Students found the problem interesting and challenging and developed a number of different models for solving the problem. Quite surprisingly, a number of students experienced difficulties in fully understanding and using the concept of average in developing their models. Most groups easily calculated the remaining reserves of natural gas in 2008, by multiplying 2.5 billion cubic meters by 15 years (1993-2008). Some groups, however, failed to understand that consumption in recent years was not 2.5. A number of students successfully used the data provided in the activity and other resources from the Web to make assumptions about the future reserves and consumption of natural gas. Two groups of students developed more coherent models, taking into consideration current reserves, how the consumption of natural gas will be increased (using data from the Web) and how the use of renewable energy sources will affect the consumption of natural gas. (see Table 1).

TABLE 1
STUDENT MODELS

Model	Number of Groups	Level of sophistication
Model A	Three	Simplified linear models
Model B	Two	Simplified models, different hypotheses
Model C	One	Coherent model, different hypotheses, model validation
Model D	One	Coherent model, different hypotheses, iterative cycles of improvement

Student solutions are summarized in the four different models presented below.

Model A

Three groups of students developed quite similar models. All these groups commenced the problem in a rather simplified way. They discussed the provided data, but partially failed to fully understand the concept of average. In discussing the problem, they reported in their worksheets that natural gas consumption will be increased. They further supported their hypothesis by explaining that due to a number of environmental and economical issues oil consumption will be decreased and as a consequence natural gas consumption will be increased.

Students reported in their worksheets that the new annual average consumption for the following years will be 3.0 billion cubic meters. None of the groups provided any support on this new figure. When asked by the researchers, a number of students reported that this increase (0.5 billion cubic meters) is reasonable. In terms of the mathematical developments, groups calculated the remaining reserves in 2009 and then divided the remaining reserves by the new average consumption, by providing simple linear functions. Their final model was: (*141.8 - (2.5*15))/3*).

One student, however, disagreed with other students in his group. He explicitly questioned the appropriateness of his group's model. He suggested incorporating into their model the possible existence of new natural gas reserves. His suggestion has, finally, a slight impact on the constructed model of his group; their new model incorporated the possible new reserves (e.g., (*141.8 - (2.5*15+NR))/3*).

Model B

Similar to Model A, two groups of students developed quite similar models. However, a number of differences can be tracked between this model and Model A. Since students did not attempted to retrieve any data from the Web, they ended by proposing two different hypotheses. Specifically, on one hand they documented that natural gas consumption might be increased. They reported that natural gas consumption might increase, since there is a global shift from oil to natural gas use. Thinking more locally, they also reported that the new reserves of natural gas in the sea between Cyprus and Egypt will also have an impact on natural gas use. According to their second hypothesis, natural gas consumption will be decreased, since there is also a global shift to renewable energy resources, like solar and wind power. They also underline the importance of the environment and they reported that people are getting more and more aware of environmental issues and this have a direct impact on non renewable energy consumption.

While students ended to the above two hypotheses, they consequently developed two different models. Their first model was similar to the one presented earlier (Model A). However, students in these two groups reported that new average will be 2.7 and 2.8 billion cubic meters respectively. Their alternate models, based on the second hypothesis, took into account 2.2 as the new reduced annual average consumption of natural gas. Surprisingly, although they discussed the existence of new reserves, students did not use this variable in their models. Of interest there was also students' lack of understanding the concept of average. For example, they did not discuss at all what the average was in 2008 or 2009, and as a consequence they claimed that 2.7 is an increased consumption figure. Finally, similar to Model A, students in these groups did not retrieve or use data from the Web.

Model C

The group developed this model commenced the problem by listing all possible factors that might have an impact on natural gas consumption. Students in this group reported the following factors having an impact on natural gas consumption: use of renewable energy sources, new laws and restrictions on oil use, natural gas price and availability, new resources, and people awareness of environmental issues.

They concluded, after a long debate within the group, that natural gas consumption will be increased. They reported in their worksheet: *"Using renewable energy sources is getting more and more popular, but possible shift from oil to natural gas will increase gas consumption, no matter the small shift to solar and wind power"*. In developing their final model, they retrieved data from the Web, indicating that 2008 annual consumption was 2.8 billion cubic meters. As a consequence, they decided to use 3.0 as the new increased average. After including the possibility of finding new resources, they concluded in the following model: (*141.8 - (2.5*15+NR))/3.2*).

The students used this model to provide further validation to their hypothesis and therefore they proposed that we can not be sure when (and if) natural gas reserves will be exhausted, since this is related to the existence of new reserves and the new annual average consumption. Quite surprisingly, students did not incorporated in their model the shift to renewable energy sources, although their explicitly discussed it. The latter was among the additional information included in Model D, which is presented below.

Model D

Model D students started the problem by listing all possible factors that might have an impact on natural gas consumption. In preparing their list they also (similar to Model C) used Web resources. Using the data provided and also data they retrieved from the Web, they concluded that the natural gas consumption will be increased. Differently from Model C group's work, students in this group found the natural gas reserves during the last 30 years and presented their results in the graph presented in Figure 1.

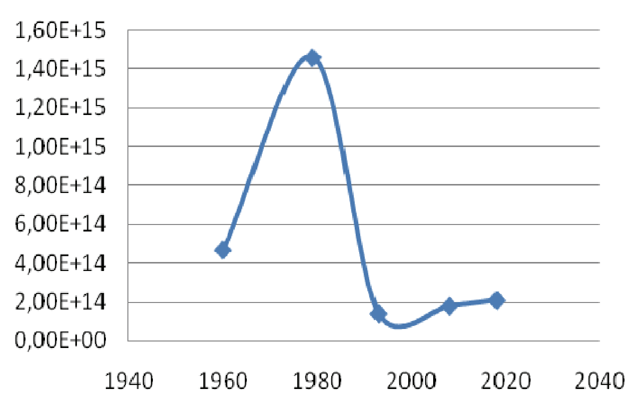

FIGURE 1
NATURAL GAS RESERVES

This work resulted in a more sophisticated model, since students documented that according to the data they retrieved the current natural gas reserves are around 200 billion cubic meters. Following data presented in Figure 1, they also reported that it looked like reserves will not be increased dramatically (they explicitly referred to graph's slope in 2010 and 2020). They documented that more or less new reserves will equal to the increase of natural gas consumption. They included in their model that the new average consumption will equal to 3.0 and they also incorporated into their model the shift to renewable energy sources. They included in their model the variable *RE*, representing the impact on average natural gas consumption from the shift to renewable energy. Students in this group ended with the following model: (*200+NR)/(3.2-RE)*. In a concluding attempt to validate and verify their model, students concluded that reserves will never be exhausted because: *"even when consumption be increased more than new available resources, the use of renewable energy will also be increased"*.

CONCLUSIONS

In this paper we have argued that the inclusion of engineering mode eliciting activities in engineering courses, even at freshmen level, can engage students in creative and innovative real-world problem solving and can assist the development of students' communication and teamwork skills. The problem we have implemented has been developed from a models and modeling perspective, which takes students beyond their usual problem-solving experiences to encounter situations that require substantial interpretation of the problem goal and associated complex data. Students have to elicit their own mathematical and engineering ideas and operations as they work the problem; this usually involves a cyclic process of interpreting the problem information, selecting relevant quantities, identifying operations that may lead to new quantities, and creating meaningful representations [5]. Because students, working in teams of four, move through iterative cycles of developing and documenting their models and solutions they have plenty of opportunities to develop their communication and teamwork skills, professional skills that are necessary for the future engineer.

The students that participated in the present study developed a number of different models that adequately solved the problem, although not all models took into account all possible data and relations. Further, it was explicit that a number of students progressively improved their results through meaningful teamwork approaches. Student models varied in the number of variables and hypotheses students took into consideration and how these variables would have an impact on natural gas consumption; the quality of these hypotheses was directly related to the extent students successfully communicated in their teams.

Substantial more research is clearly needed in the design and implementation of engineering modeling activities in introductory engineering courses and the learning generated. We need to know, for example, (a) the developments in freshmen engineering students' learning in solving a range of engineering-based problems; (b) the ways in which model eliciting activities enhance students' communication and teamwork skills; and (c) the types of engineering contexts that are meaningful, engaging, and inspiring for these learners.

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