ISSN: 2147-611X

International Journal of Education in Mathematics, Science and Technology (IJEMST)

www.ijemst.com

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To cite this article:

Kertil, M. & Gurel, C. (2016). Mathematical modeling: A bridge to STEM education. *International Journal of Education in Mathematics, Science and Technology, 4*(1), 44-55. DOI:10.18404/ijemst.95761

IJEMST
International Journal of Education in Mathematics, Science and Technology
Volume 4, Number 1, 2016 DOI:10.18404/ijemst.95761

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Article Info

Article History

Received:
7 August 2015

Accepted:
11 October 2015

Keywords

STEM education
Mathematical modeling
Project-based learning
Model-eliciting activities

Abstract

The purpose of this study is making a theoretical discussion on the relationship between mathematical modeling and integrated STEM education. First of all, STEM education perspective and the construct of mathematical modeling in mathematics education is introduced. A review of literature is provided on how mathematical modeling literature may contribute to theoretical conceptualization of STEM education by specifically addressing the professional competencies that teachers need. The discussion followed on how mathematical modeling activities and project-based learning contexts contribute to integrated STEM education by providing two research-based experiences, one of which is the model rocketry project carried out by pre-service physics teachers and the other one of which is a mathematical modeling activity solved by pre-service mathematics teachers.

Introduction

The 21st century, as a technology-based information age, brings new job opportunities, besides the future jobs demand new qualifications from the laborers. In today's world, technology based tools have been commonly used in many professions such as science, arts, business and engineering, and even in agriculture (Lesh & Doerr, 2003). Moreover, the major abilities and qualifications expected from the employees change from carrying out the routines to problem solving by understanding complex systems through constructing, describing, explaining, manipulating, and predicting (English, 2006). That is to say, the employees are expected to have problem solving and analytical thinking abilities in addition to the conceptual tools communicating and externalizing them. Recently, this fact has been more generally voiced with the need for reform in the education of STEM (science, technology, engineering, and mathematics) areas. Most of emerging jobs require competence, to some extent, in STEM and countries gradually feel the inadequacy of the existing education in STEM areas (Roehrig, Moore, Wang & Park, 2012).

From the general political perspective, STEM professional means having the necessary competencies in science, technology, engineering, and mathematics and it may seem to be simple to actualize. The report *Rising Above The Gathering Storm* published by National Academy of Sciences (NAS), National Academy of Engineering, and Institute of Medicine (2007) in United States recommended focusing on the STEM competencies in K-12 and higher education. Countries have been offered to invest in innovation for educating the future generations of STEM professionals (National Academy of Sciences [NAS], National Academy of Engineering, & Institute of Medicine, 2007; Organization for Economic Cooperation and Development [OECD], 2010). By this way, it has been supposed that countries can solve the unemployment problems by creating new job opportunities and support the development of innovative STEM workforce for the sustainability of economic growth. However, from educational perspective, we need to clarify what is indicated by STEM education, how it should be conceptualized, and in what ways it can be put into practice.

Integrated STEM education is a developing construct in education and there are different perspectives about the implementation of STEM education. *Content integration* and *context integration* models have been categorized as two models of STEM integration (Roehrig et al., 2012). Content integration means preparing a structured or flexible STEM education curriculum by which more than one discipline can be covered. Context integration, on the other hand, is putting one discipline into the center and teaching it in a meaningful way by selecting relevant contexts from other disciplines without ignoring the unique characteristics, depth, and rigor of the main discipline. For both perspectives, there are lots of controversial issues such as how to prepare teachers as implementers of integrated STEM education, how to develop and who will develop the curricular materials needed, and how to prepare and implement an integrated curriculum without changing the existing school organizational structures (Corlu, Capraro & Capraro, 2014). At this point, the literature and knowledge base of mathematical modeling in mathematics education have potentials to contribute to this emerging area (e.g., English, Hudson & Dawes, 2013; English & Mousoulides, 2011). The purpose of the current study is conducting a theoretical discussion on how the construct of mathematical modeling can contribute to the integrated STEM education. To do that, we tried to summarize the current perspectives about the STEM education first. Then, we discussed on how the knowledge base of mathematical modeling in mathematics education literature can be used as a stepping-stone for conceptualizing the integrated STEM education. Also, by providing two sample activities that are a project-based learning activity and a mathematical modeling activity as two different models of STEM integration, we discussed on the possible ways of putting the integrated STEM education into practice in accordance with the existing schooling structures.

STEM Education

Preparing youngsters to future life with the necessary qualifications has been the basic demand of the business world from educators. Education at secondary and university levels in science, technology, engineering and mathematics (STEM) areas has been discussed throughout the world in order to create more qualified workforce for a brighter economic future (e.g. Australia, UK, USA, Turkey). For instance, the US declared the political goal that reconsidering the K-12 and higher education to prepare students having strong background in science, technology, engineering and science (President's Council of Advisors on Science and Technology, 2010; 2012). Because of the political pressure of the business world, the need for reform in the education of science, technology, engineering, and mathematics fields has been discussed with the acronym STEM. The need for integrated STEM education is not a political stance of government in Turkey, but there are some individual efforts trying to put this issue on the agenda of educators and stakeholders.

Although STEM education has become one of the trend topics among the stakeholders and educators, there is not a common understanding about the basic issues (Breiner, Johnson, Harkness & Koehler, 2012; Roehrig et al., 2012). The theoretical rationale of STEM education has originated from the curriculum integration theories. Integration of curricula or integrated way of teaching seems critical for STEM education in terms of covering the interconnected nature of the four disciplines and real life. As stated by Corlu et al. (2014), there are two perspectives emerging from the curriculum integration theories about the administration of STEM education in school settings. These perspectives are; (i) integrating the correlated subjects without ignoring the unique characteristics, depth, and rigor of the main discipline, and (ii) preparing a flexible curriculum that guides the teachers.

In the conceptualization of STEM education, the most important notion is the integration of various disciplines during the practice of teaching (Breiner et al., 2012; Corlu et al., 2014). In the model offered by Corlu et al. (2014), mathematics and science education are given a central role. In that model, engineering and technology components of STEM education are limited to supportive roles. In contrast, various other researchers indicated that the most important component of STEM integration in middle and secondary levels should be the engineering education (English & Mousoulides, 2011; Hudson, English & Dawes, 2014; Roehrig et al., 2012). In their recent study, Hudson et al. (2014) indicated that engineering education should be considered as a curriculum area in its own right. The basic arguments of these researchers were that engineering education has the potential to connect across many subject areas, which may provide students with meaningful learning opportunities. Moreover, engineering education at secondary levels is believed to provide students with general information about the future career opportunities in STEM-related fields. Considering the limitations of such models, it seems difficult to provide a well-organized engineering education at primary and secondary levels. However, there are some other researchers, who interpret engineering education as confronting students with the acts of engineering. Those acts include researching, designing, and producing. At that point, project-based learning (PBL), so called as STEM PBL, has been offered as an effective instructional strategy for developing students' engineering competencies in addition to the necessary skills of other STEM disciplines (Capraro & Slough, 2008). Various properties are attributed to STEM PBL contexts such as having interdisciplinary learning objectives, ill-defined tasks, student-centered interactive group work and collaboration, involving hands on activities, and producing or designing an artifact (Han, Capraro & Capraro, 2015). According to Capraro and Slough (2008), STEM PBL contexts in which students work on multifaceted, information rich, authentic, and ill-defined tasks with well-defined learning outcomes can be used for STEM integration. The study by Han et al. (2015) showed that STEM PBL contexts contributed to the academic achievement of low performing high school students.

Roehrig (2012)'s categorization is useful in interpreting these different models through (i) content integration or (ii) context integration. Content integration means covering the big ideas from multiple content areas in a single curricular unit. In other words, content integration occurs when designing a single curricular activity or unit aiming to teach the basic ideas from all STEM fields. Because learning objectives from different disciplines are covered in a single curriculum, STEM PBL contexts offered by Capraro and Slough (2008) can be interpreted as content integration model of STEM education. In this paper, we provided the *model rocketry* project as an example for STEM PBL in the following part. Context integration, on the other hand, is about positioning the content of one discipline in the center and trying to teach that content with a problem solving approach by selecting relevant contexts from other disciplines. In context integration models, the *big ideas* of mathematics or science are covered within the engineering or technology contexts. Here, the engineering context has been borrowed and the mathematical concepts have been covered within this context. This type of integration is a stance advocated by Corlu et al (2014) for STEM education in the Turkish context due to existing teacher resistance (probably due to their inadequate pedagogical content and integrated teaching knowledge) and rigidity and centralized nature of the Turkish curriculum. Yet, many researchers indicated that, particularly in mathematics classrooms, the context integration model of STEM education could be put into practice by using the modeling activities (e.g., English et al., 2013; English & Mousoulides, 2011; Hamilton, Lesh, Lester & Brilleslyper, 2008; Roehrig et al., 2012). In particular, Roehrig and others (2012) indicated that the model-eliciting activities introduced (Lesh & Doerr, 2003) can be used as context integration model of STEM education. Further details about Lesh and Doerr's models and modeling perspective (MMP) will be introduced in the following part.

In short, many of the issues discussed about STEM education are reminiscent of the discussions on mathematical modeling in mathematics education. The majority of the arguments related to the STEM education perspective are common with the ideas stated by the community of researchers studying on mathematical modeling in mathematics education such as the need for developing students' competencies needed in this technology-based information age (English et al., 2013; English & Mousoulides, 2011; Lesh & Zawojewski, 2007; Niss, Blum & Galbraith, 2007). Furthermore, the obstacles such as the difficulty of integration into the curriculum, lack of professional knowledge of teachers, lack of curricular sources are some of the common problems indicated in the STEM education and mathematical modeling literature (e.g., Blum, 2015; Breiner et al., 2012; Corlu et al., 2014; Kaiser & Maaβ, 2007; Oliveira & Barbosa, 2009). In the following part, the theoretical perspectives of mathematical modeling will be introduced first, followed by a projection of the theoretical aspects of STEM education from the knowledge-base of mathematical modeling.

Mathematical Modeling as a Bridge for STEM Education

In general terms, mathematical modeling can be defined as the process of mathematizing, interpreting, verifying, revising, and generalizing real life situations or complex systems (Lingefjard, 2002). Lesh and Doerr (2003) describe mathematical modeling as a process of producing sharable, modifiable, and reusable conceptual tools for describing, predicting, and controlling real life situations. Mathematical modeling applications provide students with significant local conceptual developments and meaningful learning of basic mathematical ideas in real situations. In recent years, many researchers have indicated the need for modeling applications in school mathematics in order to develop students' analytical thinking abilities, problem solving abilities, and the qualifications needed in this technology-based information age (e.g., Lesh & Zawojewski, 2007; Niss et al., 2007; Talim ve Terbiye Kurulu Başkanlığı [TTKB], 2013). These are also the basic arguments indicated by the community who emphasizes the need for integrated STEM education (Breiner et al., 2012; Capraro & Slough, 2008; Roehrig et al., 2012). Different perspectives about the integrated STEM education commonly stress the usage of the well-prapared contextual and ill-defined tasks as instructional tools (Capraro & Slough, 2008; Roehrig et al., 2012). Using such kind of tasks engage students with multiple processes such as designing, constructing, analyzing, mathematizing, verifying, revising, and communicating (Capraro & Slough, 2008; English & Mousoulides, 2011). Therefore, to some extent, mathematical modeling as a process is involved in all STEM related applications. In other words, all STEM activities are not modeling activities, but students may experience the mathematical modeling process while working on many of them.

Compared to STEM education perspective, mathematical modeling in mathematics education has been studied for long years all around the world. Although there is a rich research-based knowledge and experience on mathematical modeling in education, still it is difficult to describe a common understanding of the issues of mathematical modeling among educators (Erbaş, Kertil, Çetinkaya, Çakıroğlu, Alacacı & Baş, 2014; Kaiser, Blum, Borromeo Ferri, & Stillman, 2011; Kaiser & Sriraman, 2006; Galbraith, 2012). At first glance, the appearance of different perspectives of mathematical modeling can be found in the literature (Erbas et al., 2014; Kaiser & Sriraman, 2006). According to Julie and Mudaly (2007) and Erbaş et al. (2014), there are two perspectives about the usage of mathematical modeling in teaching and learning mathematics that are seeing *modeling as content* in its own right and *modeling as vehicle* to teach mathematics. The researchers seeing mathematical modeling as a content in its own right focuses on describing and teaching the modeling cycle, the phases in modeling cycle, modeling abilities and competencies. Research studies following this tradition uses the description of modeling as the conceptual frame for describing students' and teachers' behaviors during modeling process, modeling competencies, and assessment of modeling competencies (e.g., Borromeo Ferri, 2006; Crouch & Haines, 2004; Frejd, 2013; Galbraith & Stillman, 2006; Houston, 2007; Lingefjärd, 2006; Maaß, 2006). The focus from this perspective is the teaching of mathematical modeling with its many technical details.

From the perspective of seeing *modeling as vehicle* to teach mathematics, mathematical modeling activities are considered to be meaningful problem solving situations for teaching mathematics in a meaningful way (e.g., Lesh & Doerr, 2003; Doorman & Gravemeijer, 2009). This perspective emphasizes enhancing the learning of curricular mathematics by using modeling tasks. MMP perspective proposed by Lesh and Doerr (2003) can be evaluated under this category. Lesh and Doerr (2003) describe models as mathematical descriptions of situations consisting of internal conceptual systems and representations to externalize them, and modeling as the process of developing mathematical descriptions for specific situations by using the existing models or developing new ones. MMP strongly recommends eliciting or developing students' mathematical ideas while they are working on meaningful, real life situations in place of asking them to apply already acquired or ready-made mathematical ideas in relevant systems. To do this, model-eliciting activities (MEAs) have been introduced by MMP as thought revealing activities (Lesh, Hoover, Hole, Kelly & Post, 2000). Lesh and others (2000) determined six principles that a good model-eliciting activity should have, which are reality principle, model construction principle, self-evaluation principle, model documentation principle, simple prototype principle, and model generalization principle. Model eliciting activities seems to be good examples of curricular materials for context integration model of STEM education (Roehrig et al., 2012), and they have been started to be used as engineering-based problem solving contents in various recent studies focusing on STEM education (e.g., English et al., 2013; English & Mousoulides, 2011; Hamilton et al., 2008; Moore & Hjalmarson, 2010).

The research community of mathematical modeling from both perspectives suffers from the limited usage of modeling activities in mathematics classrooms (Blum, 2015; Burkhardt, 2006; Kaiser & Maaβ, 2007; Schmidt, 2011). The researchers determined various barriers for the limited usage of modeling activities such as teachers' limited professional knowledge about the nature of mathematical modeling and the ways of using it in teaching and learning of mathematics, teachers' habits of practices, and lack of curricular materials (Blum, 2015; Burkhardt & Pollak, 2006; Kaiser & Maaβ, 2007; Oliveira & Barbosa, 2009; Niss et al., 2007). In recent studies, many researchers focused on describing and developing professional knowledge that pre-service and in-service teachers need for using modeling activities in their classrooms. The researchers from different countries determined various competencies that a teacher should have in order to implement modeling activities successfully in teaching and learning mathematics. These competencies are; (i) knowledge about modeling tasks (Blum, 2011; Doerr & Lesh, 2011; Schmidt, 2011) (ii) knowing how to organize and manage the classroom during modeling activities (Blum, 2015), (iii) ability to provide strategic interventions and interpretive listening and responding to students' thinking (Doerr & English, 2006; Doerr & Lesh, 2011) (vi) ability to recognize the unexpected ways of thinking and developing strategies to cope with crisis situations (Doerr, 2007) (vii) having the necessary mathematical and extra-mathematical knowledge (Blum, 2015), and (viii) ability to use the technological tools effectively (Johnson & Lesh 2003; Pead, Ralph & Muller, 2007).

Lack of professional knowledge of teachers is also the most challenging barrier for integrated STEM education (Breiner et al., 2012; Corlu et al., 2014; English & Mousoulides, 2011). Because many commonalities exist, the descriptions of pedagogical competencies of teachers described in modeling literature can shed light into the STEM research. For instance, teaching practices such as an emphasis on group work, managing group and classroom discussions, interpretive listening of students' emerging ideas, and being a planner, a facilitator and a guide instead of being the only source of knowledge will be the changing roles of teachers while implementing a modeling activity or in an integrated STEM classroom. Similarly, having the extra-mathematical knowledge for a teacher indicated in modeling literature is related to his/her knowledge about other STEM disciplines. That is to say, a mathematics teacher should have the necessary knowledge about other STEM disciplines (i.e., the working pedagogical content knowledge in the other discipline) in order to be able to select an appropriate context that can be used in teaching a particular mathematical concept. Knowledge about the information technologies should also be considered as an important competency for all STEM teachers. In short, the knowledge base of mathematical modeling literature focusing on professional development of teachers may provide STEM researchers with valuable information. In the following part, we provided two different instructional materials one of which is a project-based learning activity and the other of which is a mathematical modeling activity by relating them with different models of integrated STEM education. By considering these instructional materials, we, then, discussed the possible ways of integrated STEM education with the current schooling structures.

A Project-Based Learning Context as an Example of STEM Integration: The Model Rocketry Project

In this part, we will share, the model rocketry project, as an example for content integration model of STEM education which has been carried out as a content of the *Instructional Theories and Material Development* course for pre-service physics teachers at a public university in Istanbul. The model rocketry project has been executed for about ten years as a content of this course and about five weeks of the course (three hours in a week) have been allocated for this project. The general process of the model rocketry project is shown in Figure 1. At the beginning of the project, pre-service teachers have been informed about the general properties of a model rocket involving the pieces needed for constructing a model rocket and how to build or reach these pieces. Also, pre-service teachers have been informed about the model rocketry projects promoted by NASA, and the importance of model rocketry projects has been discussed in terms of teaching and learning physics concepts in a meaningful way. Pre-service teachers in the course were formed into groups of two or three, according to their own preferences and they worked in the same groups on the project.

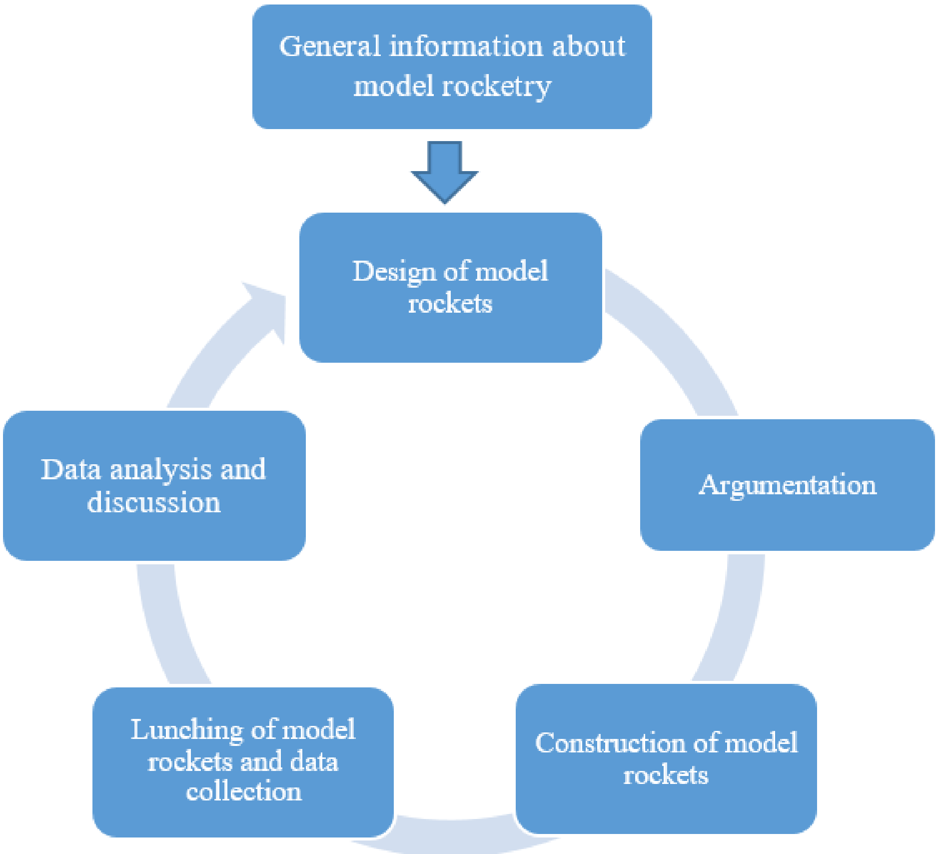


Figure 1. The process of the model rocketry project

The first phase of the project is designing a model rocket. All the groups in the course are asked to design a model rocket with the primary aim of throwing the rocket to the peak altitude. During the design process, pre-service teachers decide the general properties of their model rocket on their own. By researching from Internet, they decided on the most appropriate types of nose cone, fins and airframe. During the argumentation phase followed by the design phase, pre-service teachers theoretically discussed about the highest altitude that the model rocket can reach and calculated this altitude by using the law of energy conservation and impulse and momentum formulas. Calculating by considering the air friction and ignoring the air friction, they were also asked to discuss about the influence of air resistance on their model. During these discussions, the mathematical formulas, such as $F_s = \frac{1}{2}\rho \cdot Cd \cdot A \cdot v^2$ were discussed.

Figure 2. Fins constructed from balsa wood

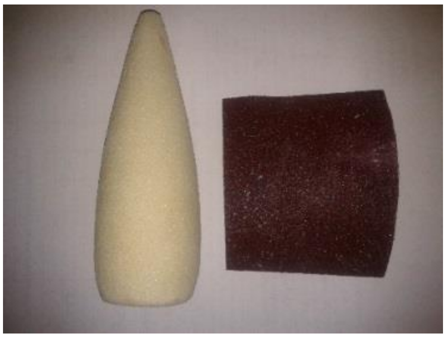


Figure 3. Nose obtained by rubbing of styrofoam

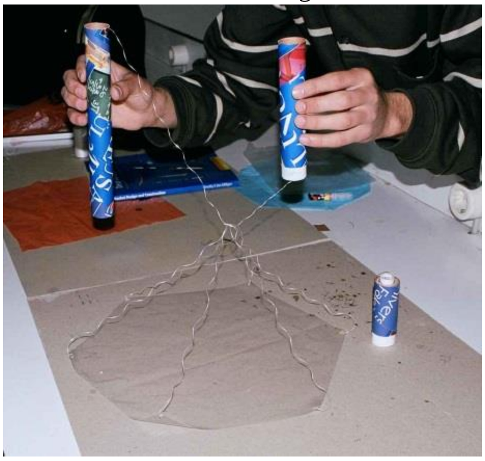


Figure 4. The hexagonal parachute

After deciding on the design and providing the basic argumentations, the next phase was constructing the model rocket. The groups constructed their own model rockets by assuring all the pieces on their own, except the machine. They built the pieces from different materials. The Figure 2, Figure 3 and Figure 4 show some of the pieces constructed by pre-service teachers. The two little fins were constructed from balsa wood and the nose of the model rocket was constructed by rubbing Styrofoam. The hexagonal parachute designed for bringing back the model rocket in safe was constructed from carry-bag and dental floss as seen in Figure 4. Pre-service teachers worked together as a team while building the pieces. After constructing all the pieces, they combined them to construct the model rocket.

The next phase of the project is launching the constructed model rocket and data collection. The constructed model rockets are lunched in an open area and the altitude values are determined with an altimeter that was mounted on the airframe of the model rocket and also calculated by using an altitude tracker. By the altimeter, the data involving the peak altitude, the maximum speed and acceleration that the model rocket reached, and the time from apogee to ejection are obtained. Additionally, the peak altitude that the model rocket reached is roughly measured by an altitude tracker which can easily be constructed from cardboard. The use of trigonometry is required while calculating the peak altitude by means of an altitude tracker. Launching a model rocket constructed by pre-service teachers is seen in Figure 5.

As the phases are briefly described in this part, the model rocketry project can be a powerful context to incorporate STEM disciplines into a challenging and motivating activity for students. Considering the STEM disciplines separately, model rocketry project involves design and construction of the model rocket which is related to engineering education. In terms of science education, students have an opportunity to apply the Newton's Laws to solve problems in real world, the laws of conservation of energy and momentum. They used trigonometry while calculating the highest altitude by means of the altitude tracker. They also reinterpreted the physics formulas mathematically that they already know. In terms of technology education, they research about the pieces of a model rocket by using the Internet and they used the altimeter as a data collection tool. For analyzing the data, they could also benefit from computer programs such as MS Excel. Moreover, such kind of projects can contribute students in developing teamwork, communication and many other social skills as discussed in STEM education.

Figure 5. Launching a model rocket

During the model rocketry project, the developments in pre-service physics teachers' conceptual understanding of many physics concepts were examined in the study by Gürel (2008). At the end of the project, pre-service physics teachers were asked what they learned during the model rocketry project, and some of the representative views were as follows:

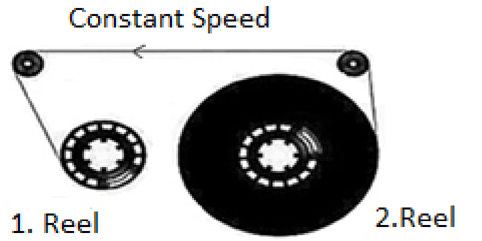
> *S1: After attending this project, I think I can interpret the Newton's motion laws more properly. I gained a holistic point of view by covering and discussing on many physics concepts in such a single activity. I think I understood the relationships between the physics concepts.*
> *S4: The model rocketry project ensured me to consider the forces that I never think about. In fact, I could analyze better the forces that I can formulize and that influence each other. I learned the relationships between various concepts such as center of pressure and center of mass.*
> *S6: It was a great experience for me. This project enabled us to observe and realize the basic concepts of physics in implementation. We also learned a good and funny project that we can apply with our students in the future. I wish, if we can design and construct the new model rocket after the first experience. It was really a good experience...*
> *S7: Seeing the physics concepts not only in theory, but also in application provided us more meaningful understanding of these concepts. At the same time, I got the idea that such a project can be used for teaching the impulse and momentum topics. It would be better if we could design, construct and lunch a few model rockets in terms of comparing the differences and deciding the better model. We continuously searched during all phases of the project and we could observe our weaknesses in practice. It was a useful experince for us.*

As can be seen on the episodes above, pre-service physics teachers indicated in common that they learned the physics concepts in context and realized the connections between these concepts. The data provided above is not related to STEM, but the perceptions of the pre-service teachers about the project that they involved may provide us with valuable information related to STEM education. Although this study was not conducted with the awareness and intention for STEM education, we can consider this experience as an example for content integration model of STEM education. During the project, pre-service teachers experienced multiple processess from different STEM fields such as designing and producing a model rocket, collecting data during the experimentation of it, and analyzing. However, the need for a set of technical materials and a qualified teacher who can help and guide students is apparent in such project-based learning contexts. The next part introduces an application of modeling activity carried out by pre-service mathematics teachers as another example for context integration model of STEM integration.

Mathematical modeling activity as another example of STEM integration

As stated in previous parts, STEM activities, to some extent, involve a mathematical modeling process. Furthermore, mathematical modeling activities have been proposed as an instructional material for STEM education (e.g., English et al., 2013; English & Mousoulides, 2011; Roehrig et al., 2012). In this part, we will discuss the possible contributions of modeling activities to integrated STEM education by providing results from a study conducted by Delice and Kertil (2015). The *Cassette Player* activity was implemented in the period of one lesson (60 min), with a group of pre-service secondary mathematics teachers attending a 2-year mathematics teacher certification program in a state university in Istanbul.

The Cassette Player Modeling Activity:
Consider an ordinary cassette placed in a tape recorder. When the tape is played, it is transferred from one reel to the other at a constant speed. Try to explain the changes in the radiuses of the roll of the tape on both reels mathematically.



(Delice & Kertil, 2015, p.638)

In the study of Delice and Kertil (2015), it has been focused on the mathematical ideas in the problem context and pre-service mathematics teachers' preferences of fluency between mathematical representations such as graphs, verbal expressions, algebraic expression or tabular have been articulated in detail. Additionally they also reported that some of the pre-service teachers came up with the idea of linear and angular speed concepts which can be considered as a byproduct. In the problem text, the *constant speed* is stressed. While pre-service teachers think about the change in radius of both reels, some of them became suspicious about how the speed can be constant. Results from individual solutions and group discussions indicated that some of the pre-service teachers accepted the constant speed as given in the problem text. A few groups decided there is a changing speed, but they could not distinguish which speed was changing. Some of the pre-service teachers decided that the speed is changing by naming it as *turning speed*. The basic argument of pre-service teachers who reached there is a change in turning speed was that the length of displacement of band (the length of released and wrapped band) is equal for both reels. An episode, from the written explanation of a pre-service teacher, provided in the study of Delice and Kertil (2015) reflecting this argument is as follows:

> S10: *When the reel A turns a "α" degree angle, it releases length of "x" unit band in "t" times. The reel B has to wrap this band (having length of "x" unit) also in "t" times. If we consider that the reel B wrapped this length by turning a "β" angle, it is clear that β>α. So, the angles α and β are directly proportional to the speeds of both reels. An increasing change in the speed of reel A and a decreasing change in speed of reel B will continue until the radius of both reels become equal. The spontaneous speeds will be equal at the time the radius become equal, and later the wrapping process will continue by the reel A will be faster than the reel B. The important point here is that the speed of band is different than the turning speed of reels* (Delice & Kertil, 2015, p. 649).

Delice and Kertil (2015) reported that, most of the pre-service teachers intuitively realized the difference between linear and angular speed concepts in the cassette player context. As can be observed from the explanation of S10, the participating pre-service teacher focused on the length of band released by reel A and the same length of band that has to be wrapped by the reel B for deciding the changing speed. This pre-service teacher also considered the measures of the central angle that both reels traced. He did not use specific terminologies as linear or angular speeds, but the last sentence in his explanation shows he could distinguish between these two concepts. He named linear speed as the speed of band, and angular speed as the turning speed of reels. Most of the pre-service teachers agreed upon this way of thinking during group or classroom discussions. However, it was interesting that none of the pre-service teachers realized or remembered the linear and angular speed concepts although they already know about them from high school and university level physics courses.

The results reported by Delice and Kertil (2015) provide us valuable information about how the significant ideas of science can be covered in together with the big ideas of mathematics in a mathematics classroom during the implementation of modeling activities. Many other studies on mathematical modeling also showed the interdisciplinary nature of the learning outcomes (e.g., Carrejo & Marshall, 2007; Doerr, 1997). During the implementation of the *Cassette Player* modeling activity in a mathematics course, students visited and realized some of the physics concepts which is the main argument of the integrated STEM education. Compared to the STEM PBL activities, mathematical modeling activities seem to be easy to implement in the current schooling structures.

Discussion and Conclusion

The need for integrated STEM education has been voiced by many scholars. Content integration and context integration models have been categorized as two models of STEM integration (Roehrig et al., 2012). Content integration means preparing a structured or flexible STEM education curriculum that guides the teachers, while context integration is defined as teaching knowledge and skills in the main discipline in an integrated way without ignoring the unique characteristics, depth, and rigor of the main discipline (Corlu et al., 2013).

The model rocketry project can be seen as a content integration model of STEM education, because it involves ideas and competencies from all STEM disciplines such as designing and constructing (engineering) of an artifact, argumentation of many of mathematical, physical and engineering ideas, and the use of information technologies while collecting and analyzing data. Model rocketry was an information rich, authentic project-based learning context for students (Capraro & Slough, 2008). These kinds of projects provide students with rich learning opportunities, but it is difficult to indicate and report them as well-defined learning outcomes. A physics teacher can define and focus on a list of well-defined learning outcomes in a model rocketry project, but how the possible learning outcomes belonging to other STEM disciplines can be accomplished. That is to say, because the project-based learning contexts cover all STEM disciplines, it is difficult to integrate into the existing curricula. In such learning contexts, collaboration among teachers became critical which is difficult in the current schooling structures. Also, professionally competent teachers are needed in order to implement such kind of multidisciplinary project-based learning environments (Breiner et al., 2012; Corlu et al., 2013). The teacher education programs should focus on how to prepare future teachers so they can collaboratively design a learning environment and carry out these kinds of teaching practices.

The second model of STEM education is the context integration (Roehrig et al., 2012). Context integration is putting one discipline into the center and teaching it in a meaningful way by selecting relevant contexts from other disciplines. In fact, by the context integration model teachers can teach in an integrated way without ignoring the unique characteristics, depth, and rigor of the main discipline (Corlu et al., 2013). Mathematical modeling activities have been offered as good examples of context integration model for STEM education (English, Hudson & Dawes, 2013; English & Mousoulides, 2011; Moore & Hjalmarson, 2010; Roehrig et al., 2012). Modeling activities are relatively small-scale and narrow learning contexts that a teacher can easily manage and it takes only one or two lesson hours to finalize. From this aspect, modeling activities seem to be more appropriate within the current schooling structures for integrated STEM education in terms of teachers, students, families, and also school administrations. Mathematical modeling activities should not be considered only for mathematics education. They can also be used in science and engineering classrooms (e.g., English, Hudson & Dawes, 2013; 2011; Hamilton et al., 2008; Moore & Hjalmarson, 2010). For instance, in the cassette player modeling activity, pre-service teachers came up with the big ideas of *linear and angular speed* although the main focus of the activity was not these concepts. As indicated by Delice and Kertil (2015), by modeling activities, the related mathematics and physics or other STEM concepts can be taught concurrently within a well-chosen learning situation. To do this, the teacher should have the necessary professional knowledge in supporting the emergent ideas from other disciplines, which means that he/she should have knowledge at least about the basic ideas of other STEM disciplines.

At this point, teachers' professional knowledge became the critical issue again. Teachers lacking of professional knowledge about mathematical modeling have been voiced in the modeling literature and the need for professionally competent teachers for increasing the widespread use of modeling activities in the classrooms has been emphasized (e.g., Burkhardt & Pollak, 2006; Kaiser & Maaβ, 2007; Oliveira & Barbosa, 2009; Niss, Blum, & Galbraith, 2007). This is also the primary need for integrated STEM education. Mathematical modeling literature determined some specific professional competencies that teachers should have in order to implement modeling activities in teaching mathematics. Teachers' changing roles in managing the classroom such as shifting evaluative type of intervention to interpretive type of intervention, having the necessary knowledge about the information technologies, having extra mathematical knowledge belonging to other STEM disciplines are some of these competencies. The professional development programs designed to improve teachers' competencies for mathematical modeling (e.g., Borromeo Ferri & Blum, 2009; Maaß & Gurlitt, 2009; 2011) can be used as a stepping stone in designing effective professional development programs for STEM education.

Moreover, there are limited sources as good curricular examples of STEM integration that teachers can follow (Roehrig et al., 2012). Mathematical modeling activities can also be considered as good curricular examples of STEM integration, and also they are more appropriate and easy to apply within the existing schooling structures. In this paper, we tried to put into words the coinciding goals of mathematical modeling in education and integrated STEM education. We mentioned the need for professional development of teachers that the knowledgebase of mathematical modeling introduced and we tried to reflect upon the integrated STEM education. Although we reported mathematical modeling literature as a bridge to STEM education, even a set of more problematic issues can be listed about the integration of STEM education. If we consider the integrated STEM education as a well-defined goal, there are several milestones on this ill-defined journey.

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