Extending K-12 Industrial Engineering Outreach Programs and Accessibility Using Simulation

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Abstract

Relevant Education for Math and Science (REMS) is a university outreach program designed to aid students in grades 5-12 with making connections of mathematical methods and scientific principles with practical engineering applications, and to help spark their interest in STEM fields. This outreach program consists of a set of interactive experiences involving industrial engineering problem solving activities including assembly line balancing, recycling, and order picking, among others. In this paper, we present the methodology for utilizing systems simulation models to extend the REMS outreach program to students/teachers that may not be able to participate on-site in the university labs. A multiphase design approach is taken for the development of the in-lab and on-line content. The experiences are mapped to specific math and science concepts at elementary, middle, and high school levels. In addition to demonstrating the application of math and science to industrial engineering problems through simulation, the applications also illustrate simulation as a fundamental industrial engineering tool. Finally, an assessment of the REMS current in-lab and on-line (simulation-based) experiences is presented to compare/contract the modes of delivery and outcomes.

Keywords
STEM education; outreach programs; simulation; and industrial engineering

1. Introduction

Outreach programs have been developed by universities and organizations throughout the U.S. to expose K-12 students to science, technology, engineering, and math (STEM) fields with the intention of increasing their interest in pursuing productive careers in these areas. Many outreach programs take the form of involving students in STEM camps, field trips, etc. where student conduct hands-on experiments and other activities. Other outreach programs engage students through on-line videos, demonstrations, and lessons.

In this paper, we present a novel university led STEM outreach program called Relevant Education for Math and Science (REMS). The REMS program conducted by the Kate Gleason College of Engineering at Rochester Institute of Technology (http://www.rit.edu/kgcoe/rem) is designed to aid students in grades 5-12 with making connections of mathematical methods and scientific principles with practical engineering applications, and to help spark their interest in STEM fields. This outreach program consists of a set of interactive experiences involving industrial engineering problem solving activities including assembly line balancing, recycling, and order picking, among others. To extend the outreach program to students that may not be able to participate on-site in the university labs, parallel on-line versions of the activities have been developed. In particular, several of the on-line activities utilize simulation models to (a) demonstrate the systems and issues that engineers encounter in industry; and (b) to provide realistic data sets that can be utilized to calculate system performance measures. Furthermore, the simulation models themselves demonstrate how simulation can be used as an analysis tool to study the behavior and performance of complex systems.
The remainder of the paper is organized as follows. Section 2 provides a summary of the relevant related work. An overview of the REMS outreach program is described in section 3. The design, development, and assessment of the on-line simulation-based activities is presented in section 4. Finally, concluding remarks are expressed in section 5.

2. Related Work

STEM outreach programs have been growing as studies have shown a national need to get K-12 students involved in math and science activities with the object of encouraging students to pursue careers in STEM fields. The STEM outreach program at the Colorado School of Mines utilizes a summer camp format for K-12 students that is followed by providing graduate students support in the K-12 classrooms during the academic year [1]. The “STEM Academy” developed and run by Ohio Northern University provides field trips for students to introduce them to engineering through interactive science activities [2]. The Arizona Science Lab at the University of Arizona also runs a fieldtrip based STEM outreach program the offers K-12 students to participate in activities involving the engineering design, build, and test cycle [3]. These are just three examples of the various engineering outreach programs offered by universities across the U.S. that involve hands-on lab based activities to promote STEM careers.

In addition to lab based activities a number of organizations provide ideas for STEM activities for K-12 students through the Internet. Examples of these web-based programs include: TEACH Engineering [4] (https://www.teachengineering.org/) which provides over 1000 theme-based curriculum ideas for K-12 teachers that consist of standards-aligned engineering lessons and interactive activities for use in science, engineering, and math classrooms; Design Squad Nation [5] (http://pbskids.org/designsquad/) provides lesson plan ideas, activities, and video profiles for use in the classroom or for use at home; and Try Engineering [6] (http://tryengineering.org/) provides STEM resources for students, parents, teachers and guidance counselors.

The REMS outreach program builds on these ideas for hand-on STEM activities and directly links the engineering activities to specific K-12 curricular subjects. The REMS activities also provide lesson plans for teachers in both in-lab and on-line formats.

3. Overview of the REMS Outreach Program

The goals of the REMS program are to: (a) create an effective math and science curriculum for grades 5–12 with a hands-on industrial engineering focus; (b) increase the number of 5th–12th grade math and science teachers using age-appropriate teaching modules linking math and science to real-world industrial engineering challenges; and (c) increase the number of students who have access to fun, age-appropriate hands-on activities that link math and science to real world industrial engineering problems [7-8]. The curriculum activities are designed to provide students with an improved understanding and retention of mathematical and scientific concepts by utilizing relevant lessons based upon real-world scenarios.

REMS currently consists of nine industrial engineering related activities that are available in both in-lab and on-line formats. A list of these activities is shown in Table 1. The program includes activities in contemporary manufacturing, distribution and logistics, and healthcare systems. Each of the activities have been developed for at three levels – elementary (grades 5-6), middle (grades 7-8), and high (grades 9-12) school, and are mapped to specific math and science curricular subjects at each grade level, respectively. An example of this curricular subject mapping for the Household Container Recycling activity is displayed in Figure 1. Complete information about each activity along with detailed lesson plans can be found at the following link: http://www.rit.edu/kgcoe/rems .

When the activities are conducted in-lab, students work together in teams. The lesson typically begins with an overview of the activity followed by hands-on instruction/training as required and then team execution of the scenario. During the activities students observe the system and collect data on system performance. Subsequently, students utilize the data to perform calculations and draw conclusions about the system. Then, based on their experience, students generate alternatives to improve system performance. The alternatives are then implemented, the activity is executed again, students observe the system and collect data, and finally assess how/why the system did (or did not) improve.

Each activity consists of lesson plans for each grade level that can be completed within approximately 45-60 minutes. The lesson plans contain instructions to lead the teacher through the lesson along with worksheets that correspond to the math and science concepts involved in the engineering scenario.
Table 1. REMS current outreach STEM activities

<table>
<thead>
<tr>
<th>REMS Activities</th>
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<tbody>
<tr>
<td><strong>Contemporary Manufacturing Activities</strong></td>
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<tr>
<td>1) Skateboard Assembly – Cycle Time **</td>
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<tr>
<td>2) Skateboard Assembly – Line Balancing **</td>
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<td>3) Skateboard Assembly – Performance Testing</td>
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<tr>
<td><strong>Distribution and Logistics Activities</strong></td>
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<tr>
<td>4) Meal Picking **</td>
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<tr>
<td>5) Ergonomic Design</td>
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<tr>
<td>6) Household Container Recycling **</td>
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<tr>
<td><strong>Healthcare Systems Activities</strong></td>
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<tr>
<td>7) Patient Flow</td>
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<tr>
<td>8) Ergonomic Picking</td>
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<tr>
<td>9) Hazmat Disposal</td>
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** Denotes simulation-based on-line activities

On-line activities have been developed to parallel the in-lab activities. The on-line activities enable access to teachers and students across the globe. The on-line activities are designed to capture the essence of the activities conducted in the lab. For several of the activities (specifically, activities 3, 5, 7, 8, and 9) a list of material that can be found in a typical classroom is provided so the teacher can set up and run the activity in a similar manner as that run in the lab. In cases where setting up and running that activity may not be possible in a typical classroom, computer simulation models have been developed to convey the system of interest (specifically, activities 1, 2, 4, and 6). In the next section, we discuss the design and development of the simulation-based on-line activities.

![Household Container Recycling](image)

Figure 1. REMS household container recycling activity and associated curricular subject [8]

4. Design, Development, and Assessment of Simulation-based On-line Activities

To enable global access to the REMS activities, on-line activities were designed and developed to capture the essence of the in-lab activities. However, for several of the activities replicating the in-lab activity in a classroom would require materials that are not available in a typical classroom and would require significant time and effort to set up. For these cases, we utilize a simulation-based approach to represent the dynamic systems. In particular, the lesson plan is adapted to utilize videos of the in-lab system and the simulation model animation in place of the physical in-lab activity.

The design and development of the in-lab and on-line activities involved first developing the in-lab activity followed by the development of the corresponding on-line activity. Each of these phases involved a four step process including: (1) Development; (2) Alpha Testing; (3) Beta Testing; and (4) Production/Continuous Improvement. In the Development stage, the activity was conceptualized and a prototype was developed. The Alpha Testing stage
involved running the activity within the design group to evaluate and address areas of improvement. The Beta Testing stage involved testing the activity among small outside groups of students and teachers to obtain feedback on all aspects of the activity. Finally, in the Production/Continuous Improvement stage, the activity was made available through the REMS program to student groups and teachers. To provide a mechanism for assessment and continuous improvement, surveys are provided for participants and teacher to provide feedback on the effectiveness of the activity and for opportunities for improvement. In terms of timing, the on-line activity development cycle followed the same four development stages but intentionally lagged behind the in-lab development.

In the following sections, we illustrate the various uses of simulation in the on-line activities and provide an overview of the assessment results involving these activities.

4.1 Skateboard Assembly, Cycle Time and Line Balancing Activities
To engage students in a manufacturing activity, we utilize a skateboard assembly line which provides a product that is fun and familiar to students. The cycle time activity demonstrates the time it takes to assemble a part or product in an assembly line. The line balancing activity demonstrates how unbalanced assembly lines can produce bottlenecks and impact both productivity and worker utilization, and by balancing the line how productivity can improve. Videos are used to illustrate the individual tasks needed to assemble a skateboard. In addition, a simulation model is used to show the dynamic behavior of the system. The video of the simulation animations shows the build-up in work-in-process inventory, the variability in processing times, as well as observations of station cycle time, utilization, and number of skateboards produced. Figure 2 shows a frame from the video of the skateboard assembly process and a frame of the animation video.

In addition to providing a visual representation of the system, the simulation model is also used to generate data sets. For the cycle time and line balancing activities, the simulation provides data sets that are used in the worksheets that accompany the lesson plan to demonstrate the application of curricular subject including calculating averages, percent change, cumulative percent change, and solving linear equations, among others.

4.2 Household Container Recycling
The household container recycling activity involves the process of sorting common recyclable containers at a recycling center. A belt conveyor transports the containers in front of a series of individuals responsible for sorting the material into the appropriate bin. Through this activity students can evaluate the performance of the system such as the trade-off between the number of personnel working on the sorting line and the quantity of material that can be sorted. A snapshot of the simulation model animation is shown in Figure 3 along with a data set produced by the simulation model. This activity allows students to engage in applications of curricular subjects including calculations with money, weights and weight unit conversions, etc. Alternative simulation models are available that can show how the process can change with 2, 4, or 6 workers including the number of different items each person is responsible for sorting and the quantity that can be sorted.

![Figure 2. Skateboard assembly on-line activity: (a) students engaged in lab video; (b) systems simulation video](image-url)
4.3 Meal Picking

The meal picking activity provides a scenario that demonstrates picking orders in a warehouse. The activity utilizes three alternative picking systems that illustrate how logic and technology can help to improve productivity. The first system represents an unordered manual pick list. The second system represents an ordered pick list. Finally, the third system represents a pick to light system. Here again, the simulation models provide both a visual animation of the three systems alternatives as well as data sets that can be used to perform calculations and compare system performance.

4.4 Assessment

The assessment of the in-lab and on-line activities are conducted through surveys which are administered following participation in the activities by both students and teachers. The survey instrument includes the following statements to which students responded:

1. Activity was interesting and fun.
2. Activity increased my understanding of how math/science is used to solve real-world engineering problems.
3. Activity showed a connection to math/science classes.
4. Activity will motivate me to be more interested in my math and science courses.

Students respond to the statements on a scale corresponding to how much they agree or disagree with the statement. Responses include the following: Strongly Agree, Agree, Neutral, Disagree, and Strongly Disagree. At this point, we have collected over 1300 survey responses from students and teachers that participated in the in-lab and on-line activities.
activities. Here, we present an overview of the survey results corresponding to the on-line REMS activities that utilize simulation as a central part of the activity. For a more detailed discussion of the overall survey results of the REMS activities please see [7].

For the on-line activities we have a total of 698 survey responses from student participants. For the purpose of presenting a summary of results, we have aggregated the responses from the four simulation-based activities discussed in this section (activities 1,2,4, and 6) as well as the responses from the five activities that utilize physical student interaction to perform the activities (activities 3,5,7,8, and 9). Of the responses, 386 surveys were collected for the simulation-based activities and 312 surveys were collected for the other activities. The results of these surveys are presented in Figure 5.

Overall, the survey responses for the on-line activities were quite positive. In particular, students seemed to find the activities fun, increased their understanding in how math and science relate to engineering problems, as well as showed a connection to their math and science classes. The last question that relates to whether the activity motivated them to be more interest in math and science, fell in the 50-60% range. Although this was lower than the other responses, we feel that this is important based on one activity. In comparing the simulation-based activities with the other activities it is interesting to note that there does not appear to be a large difference between the two methods of delivery. Given this set of initial data, a further study comparing simulation-based outreach activities with traditional hand-on physical activities may be a candidate for future research.

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**Conclusion**

The REMS outreach program provides an opportunity for students to make connections and better understand the relationship between engineering applications and math and science curricular subjects in a fun and interactive manner. By using both in-lab and on-line activities allows for a broader dissemination and accessibility for students and teachers to engage in the REMS program. Furthermore, we have demonstrated that by utilizing a simulation-based approach for activities that may be complex in terms of material, set-up, and time provides a suitable substitute for the hand-on physical activity. In addition, the simulation itself provides students the opportunity to see how dynamic models can be used to study systems.

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