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## Systems Engineering Educators Workshop

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# Systems Engineering Educators Workshop

## Abstract

A Systems Engineering Educators Workshop was developed with a target audience of middle school and high school teachers. The objective was to introduce topics that could be easily brought into middle and high school classrooms with active learning exercises related to industrial and systems engineering, with an emphasis on the aerospace industry. Teachers learned concepts of systems engineering, design notebooks and engineering drawings, reverse engineering, transportation optimization problems, and shortest path network problems. They also toured a local distribution center. Several of the activities were based on engineering education websites, and information about further resources was included so that the teachers could continue to integrate more engineering content into their classrooms. For the activities that were introduced during the 2-day workshop, materials were provided to help the teachers adapt the activity for their classroom, demonstrate sample student worksheets, and link to K-12 grade level expectations or standards. Graduate and undergraduate engineering students were hired to work with the faculty on program development and recruiting, administration of the program, and follow-up during the school year. To entice K-12 teachers to participate during their summer break, a stipend was provided for up to ten participants. A project work site was set up online to allow the teachers to continue to communicate as they implement the activities in their classrooms, and provide further feedback and implementation assessment with different settings. Feedback after the workshop was very positive, and the organizers hope to repeat and expand the program.

## Introduction and Format

The motivation for this workshop arose from a desire to introduce more K-12 educators to concepts of systems engineering, in an effort to ultimately attract more students into this field. Previous research and experience has shown that if K-12 educators are not familiar with or confident in basic engineering concepts or specific engineering disciplines, they will not be able to effectively encourage their students to pursue engineering as a career.<sup>1</sup> Many efforts have focused on developing improved curricular materials for K-12 engineering education,<sup>2,3</sup> and some of these studies have specifically looked at systems engineering and systems thinking in the K-12 classroom.<sup>4,5</sup> Many K-12 educators encourage certain students to pursue engineering degrees, but do not necessarily incorporate engineering concepts into their normal classroom lessons and do not always include different types of engineering, such as industrial and systems engineering.

A two-day workshop was planned, including a plant trip and several activities that explained and demonstrated systems engineering. The funding was provided through a grant from NASA, so throughout the workshop the participants were shown how systems engineering is present and important in the activities of NASA. In addition, an effort was made to relate systems engineering activities to everyday experiences of the teachers and their students. It was shown that problems are solved by systems engineers on a day-to-day basis, which affects the efficiency and effectiveness of familiar systems such as transportation systems, distribution systems, and manufacturing systems.

For each of the specific workshop activities, a “train the trainer” format was used. A presentation was given which the teachers could ultimately use in the classroom, targeted at middle or high school students. Teachers were encouraged to adapt the presentation as needed to fit with other lesson plans and units that they are already required to cover in their classrooms. Handouts that could be adapted for use by students in different grade levels were also provided. Finally, a teacher handout was provided which included materials lists, background information, tips and tricks for successfully running the activity. The website, [www.teachengineering.com](http://www.teachengineering.com), was used as a significant reference for the activities, especially to format the student and teacher handouts, and to help link the goals and primary lessons of each activity with the relevant K-12 state education standards.<sup>6</sup> The Teach Engineering website was produced through collaboration between five universities, the American Society for Engineering Education, and the National Science Foundation. Standards and grade level expectations that are currently in place at local school districts were referenced in all workshop materials, while recognizing that many states are in the process of transitioning to Common Core State Standards in English Language Arts and Mathematics.<sup>7</sup> The teacher participants were also given a list of other resources where similar pre-engineering activities can be found including the Teach Engineering website, the funding agency’s educational website, relevant PBS Kids engineering websites (Design Squad and Zoom, etc), the Society of Women Engineers websites, and others.

The pilot offering of this workshop was limited to ten participants due to funding constraints. The participants were recruited through emails to local principals, science and math coordinators, as well as emails through the university’s education department. Responses were accepted on a first come, first served basis until the limit of ten participants was reached. The final participant list was equally split between middle school (grades 5-8) and high school (grades 9-12) teachers. Of the ten teachers, seven were science teachers and three were math teachers, with one person also covering social studies. They represented seven different school districts in the region and each teacher who participated received a stipend to compensate them for their time during what would normally be their summer vacation. All of the workshop materials were also distributed on a flash drive that the teachers left with at the end of the workshop.

One important goal of the facilitators was to demonstrate low-cost hands-on activities that could be easily adapted in a wide variety of grade levels and classroom settings. Initially, a Lego-based exercise had been considered, and there are a great many resources available for such engineering education modules. The practicality and economic feasibility of these exercises, however, is limited when the typical supply availability and budgets of most classroom teachers is considered. Instead, the activities which were ultimately included in this workshop each had a projected cost of only \$0-\$2 per student. Suggestions were given on how each of the activities could be used at lower or higher grade levels, and time was provided during the workshop for the teachers to discuss how they could implement similar activities in their own subject areas and school settings.

## **Plant Trip**

The first activity of the workshop was to visit the distribution center for a regional chain of stores. The Director of Logistics and Distribution provided a company overview and a tour of

the facility including receiving, shipping, and warehouse locations. Most of the teachers had not previously visited a distribution center and had not spent much time thinking about where the products that they bought in local stores originated or how such items were transported across the country and world.

Originally, this plant trip was envisioned for the second morning of the workshop, but due to scheduling constraints had to be held on the first morning. This ultimately worked out, however, since the teachers were able to go directly to the facility prior to coming to campus for the remainder of the workshop. Also, the plant trip provided a common frame of reference for all of the participants when principles of systems engineering were later introduced throughout the workshop. Immediately following the plant trip, an introductory session described basic definitions and concepts of systems engineering, and related those concepts to warehouses, material handling, transportation and supply chain networks, and demand forecasting.

### **Universal Language Workshop**

The Universal Language of Engineering Workshop combined basic engineering drawing concepts, design notebook guidelines from undergraduate course materials, communication activities that have been used as team-building activities with middle school students, and curriculum materials from the Teach Engineering website which were adapted for the student and teacher handouts.

The first step was to review some concepts of engineering drawings, design criteria, design notebooks, and patent information. Reasons why engineers keep design notebooks were discussed, as well as format and presentation recommendations. Pairs of participants were then given a task of designing a lunar rover vehicle that would protect large marshmallow “astronauts.” The materials were mini marshmallows and office supplies such as cardstock, paper clips, paper drinking cups, straws, index cards, scotch tape, and scissors. Before touching any of the materials, however, the participant pairs needed to design their vehicle and produce an engineering drawing using graph paper which was also provided. Once they had time to document their design, the resulting drawings were exchanged with a different pair of participants. It was the task of the second group, who had received the exact same set of materials, to build the design based only on the engineering drawing that was provided. Needless to say, participants had some degree of difficulty in building their colleagues designs.

The goals of this exercise in a classroom would be to emphasize engineering communication as a part of the design process. Students gain practice in basic skills of engineering drawing and concepts of mathematical scale. More importantly, however, students would learn the steps that engineers and designers use while developing products and communicating those solutions to manufacturers and end users. This activity could be used in upper elementary classrooms such as grades 5-8, as suggested by the Teach Engineering website, but the teacher participants agreed that variations of this exercise could easily be used in their middle school and high school classrooms for a wide variety of subject areas.

## **Improving the West Corridor Workshop**

The Improving the West Corridor workshop explored the relationships of components in a system and how a system can be adjusted to meet demands. The system that is explored is the “West Corridor,” a model of a segment of a real public transportation system in Colorado. “Real-time” transit data in the online FasTracks Living Lab<sup>8</sup> is first used to evaluate whether the West Corridor is meeting design requirements. Students then suggest improvements and evaluate how these improvements will affect the system performance. Activity sheets, provided by FasTracks, focus on the concepts of establishing design criteria, graphing data, analyzing data, and improving the system.

Participants in the workshop were given time to familiarize themselves with the FasTracks Living Lab in a computer lab. Each participant had their own computer, but in a classroom setting it would be possible for students to work in small groups at a single computer. There are online user guides for the FasTracks Living Lab simulation, however, teachers are encouraged to also experiment with the program on their own. This specific activity happens to model a transit system, but it illustrates how system engineers can manage and operate large-scale systems of people, materials, equipment, information, and energy. The participants saw first-hand how systems engineers use math and computer models to represent system components and constraints, and then seek to optimize the performance in terms of cost, productivity, or efficiency.

The Improving the West Corridor activity was designed for grades 9-12, however this activity can be adjusted for a middle school setting. There are five small activities in the complete West Corridor set, but they can be used individually or integrated depending on time and technology constraints. One large benefit is that there is no monetary cost to run this activity. Participants were excited by the opportunity for this activity to cut across disciplines of math and social studies, while also introducing engineering concepts, as long as they could arrange sufficient time in a computer lab for their students.

## **Engineering in Reverse Workshop**

The Engineering in Reverse workshop was adapted from an exercise that has been successfully led with middle school girl scouts at a recurring annual workshop. Supporting materials for the student and teacher handouts were found at the [www.teachengineering.com](http://www.teachengineering.com) website and modified. On the Teach Engineering website, it is suggested that teams of middle school students in grades 5 through 8 should each be given push-toys to predict and draw the internal components, take them apart to determine how they function, and make suggestions for improvement. Instead of push toys, in the girl scout workshop, and subsequently this Systems Engineering Educators Workshop, random broken household appliances or devices are used. This reduces the cost for the teachers, in that students can be encouraged to bring in broken objects from home. Alternatively, teachers can save up objects of their own, or request donations of broken items from fellow teachers, friends, or neighbors, in case all students do not bring in their own items. Devices which were taken apart at this workshop included a microwave oven, television, coffee maker, and computer mouse. Smaller, common household objects work better for younger students.

The first step is for students to observe the object, consider user needs, and predict what types of components and mechanisms might be inside of the device that they are about to take apart. They draw these predictions, using the knowledge they might have gained from the Universal Language Workshop. Then in small groups they carefully take apart the device, considering what components are inside and how they work together. The students are encouraged to consider the materials that the components are made from, and how those components were manufactured and assembled. Students are also asked about possible redesign options and improvements to the existing device. Finally, an optional module includes linking this activity with a discussion of recycling and sustainability, considering the materials that the product is made of and how these materials affect the environment when the product is disposed.

The primary expense of this workshop is in a variety of small hand tools such as screwdrivers and allen wrenches which can be used to take the devices apart. Identical small toolkits of three different varieties were purchased which can be used at future workshops. In addition, it was offered that any teacher participant who wanted to run this activity in their classroom could sign out and borrow these toolkits in the future. In this way, resources can be shared between districts, still funded by the grant agency, and teachers can introduce a new meaningful exercise in the classroom for essentially zero investment.

Feedback from students who have participated in this exercise in the past has been overwhelmingly positive. Discussion with the teachers pointed out that students are often not encouraged to take apart or break items at home. Thus, when given the opportunity to explore mechanical devices and systems, they are encouraged and excited to find out what is inside and how it works.

### **Best Layout and Shortest Path Optimization Workshop**

The best layout and shortest path activities both focused on introducing the concept of optimization to the participants in a format that was easy to comprehend and relate to common experiences. The best layout activity first introduced the problem of traffic between gates at an airport, and then expanded the problem to consider designing factory layouts, instrument layouts on an automobile dashboard, or chip location on a printed circuit board. A problem based on a from/to chart with six locations was given, including frequencies of trips between each location. Discussions of “cost” and “distance” were used to introduce an algorithm for planning the layout in an optimal manner, including measures of optimality. Most of the teachers were unfamiliar with the “Solver” capability in MicroSoft Excel and were excited to learn that it was a free add-on that they might have access to in their own schools.

In the second half of this activity, the participants were introduced to the concept of shortest path networks, and shown the algorithm for calculating distances at each node of the network. This was initially demonstrated on the computer, but was also enhanced through the use of hands-on peg-boards that represented the same network of nodes and distance arcs. The boards used a pin or peg at each node, and a string was attached to the starting node. The string could be used to compare and measure the distances of various alternative paths through the network.

The importance of shortest path network problems was illustrated with a link to environmental issues, including the price of fuel and the efficiency of vehicles. This related directly to some of the comments that had been made earlier in the workshop during the tour of the distribution center. The teacher participants were able to see how optimizing a network can have positive benefits on the environment, as well as cost and efficiency benefits for the various types of systems that are represented.

### Feedback and Conclusions

The response to the Systems Engineering Educators Workshop was very positive. At the end of the workshop, a handwritten survey was given, and a follow up survey was distributed over email six months later. In the exit survey, 100% of the ten teachers said that they felt the workshop would help their teaching in the future, in courses such as physics, physical science, genetics, social studies in collaboration with the science teachers, math, geometry, probability and statistics. Of the ten teachers, 8 definitely planned to use workshop activities in the classroom, one participant was not sure, and one did not. The most popular activities for future inclusion in the classroom were the Shortest Path (9) and Universal Language of Engineering (8). The other activities, Engineering in Reverse, Best Layout, or Improving the West Corridor each received 3 or 4 responses. All ten of the teachers felt that the activities could be used for teaching teamwork and problem solving skills. Nine of the ten teachers thought that they could be used for teaching communication, seven out of ten for basic concepts in engineering, and five out of ten for industrial and systems engineering. The other respondents all said that they were “not sure” if they would use the activities for teaching the above concepts and skills.

The teachers were also surveyed regarding their experience and perspective about incorporating engineering concepts into K-12 classrooms. Table 1 shows their degree of agreement with statements which generally show a large affirmation for the teaching of engineering concepts at the middle school and high school level. In addition, following the activities most of the participants agreed that engineering concepts could help students attain required math and science standards, despite the fact that half of the participants had not previously taught engineering concepts in their classes.

Table 1: Survey Responses for Teaching Engineering Concepts in K-12

	Strongly Disagree	Somewhat Disagree	Somewhat Agree	Strongly Agree
I previously taught engineering concepts in my classes	0	5	3	2
Engineering concepts should be taught in elementary school classes	0	0	7	3
Engineering concepts should be taught in middle school classes	0	0	2	8
Engineering concepts should be taught in highschool classes	0	0	1	9
Engineering concepts can help attain required math standards	0	0	2	8
Engineering concepts can help attain required science standards	0	0	3	7

In the qualitative response section of the survey, participants listed interesting new learning from the workshop, which included the concept of adapting engineering content from a university to other educational levels and an increased interest in seeking out connections between math, science, and engineering. Aspects of the workshop that the teachers had difficulty with included the computer skills needed to successfully implement the shortest path or best layout optimization, and the West Corridor activities. All of the participants reported that they would recommend this workshop to a colleague and several expressed interest in having follow-up support including assemblies for students at their schools, borrowing resources such as the shortest path peg-boards and reverse engineering toolkits, and having continued communication with the facilitators and each other.

### **Follow-Up**

A follow-up survey was sent via email five months after the completion of the workshop to see if teachers had incorporated any of the systems engineering concepts or activities in their classrooms. The following five questions were asked:

- 1) Did you use any of the activities in your classrooms during the fall? If so, which activities for which classes? If not, why?
- 2) Did you use any concepts that you learned about systems engineering or otherwise in the classroom this fall? If so, what concepts in which classes? If not, why?
- 3) Do you plan on using any of the activities or concepts from this workshop in the spring?
- 4) Are there any additional resources that you need from us to bring these concepts into the classroom?
- 5) Do you have any additional comments?

Five of the ten teachers responded. Four out of the five teachers have already incorporated an activity into their curriculum, while the last teacher plans on doing so in the Spring. The activities that were described as being successful in the classroom were the Universal Language of Engineering, Engineering in Reverse, and the Shortest Path. Some of the teachers mentioned using a variation of the activities to better incorporate the material into the classroom. For example, one teacher used the shortest path and best layout activity concepts to help students conceptualize circuits.

Some teachers noted the desire to incorporate the Improving the West Corridor activity into their curriculum, but could not due to a lack of computer availability. Additionally, teachers mentioned that because teaching requirements are so specific, it is often difficult to use outside activities.

Future support that the teachers were looking for included information on engineering field trips that would help students understand the connection of classroom concepts to real-life situation, using the shortest path and best lay-out boards, and troubleshooting access from the workshop providers.



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