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From College to K-12: Adapting Industrial Engineering Classroom Exercises for Outreach Purposes

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Abstract

Outreach activities are imperative in the recruitment and development of young engineers, a key demographic in our culture's future technological advancement. According to the U.S. Department of Labor, science and engineering related fields account for 50% of our country's sustained economic growth but only 5% of the U.S. workforce. In addition, the percentage of the world's scientists and engineers that live and work in the United States has shrunk dramatically in recent years, dropping from 40% to 15% in the last three decades. In order to keep up with the societal innovations taking place around the world we need more engineers; therefore, additional resources must be allocated to recruitment and outreach. Recruitment activities specific to industrial engineering suffer from an additional obstacle: most students have no idea what industrial engineering is. It is, therefore, important that any outreach exercises are as specific as possible while remaining understandable. They must go deep enough into the subject to allow students to recognize the ultimate goal of industrial engineering, to increase efficiency, without becoming too technical for a young audience. A practical way to achieve this balance is through the modification of successful classroom assignments. This work will discuss several activities that have been successfully used for K-12 student outreach at the University of Arkansas and are based upon undergraduate class exercises. Each project will be presented in detail along with its corresponding course assignment in order to motivate the exchange of creative ideas and develop a framework for the adaptation of additional outreach activities.

1. Introduction

Many people, particularly K-12 students, misunderstand what engineering is. In fact, Anderson and Gilbride[1] found that less than one-third of high school workshop attendees were able to correctly describe engineering. This simple fact alone motivates the need to focus on the development of effective recruitment activities for K-12 students. Providing students with a basic understanding of engineering concepts can often be challenging due to the balance between learning and fun that is required in at any outreach event. If the goal is to spark interest and encourage students to seriously consider a career in engineering, they cannot be bored or feel like the material is too difficult. It is, therefore, important to ensure that the activity is interesting, appropriate for the participants, and above all, fun.

Industrial engineering outreach faces an additional challenge. Most first year engineering students at the University of Arkansas have no idea what industrial engineering is. For this reason, it is even more important that any exercises utilized for recruitment are based firmly in industrial engineering concepts while still considering the capabilities of the students. For example, a common activity aimed at introducing mechanical engineering involves building cars out of interesting materials, such as food. Because students have a better initial idea of what a mechanical engineer does, this project is an effective one that is fun for students and reinforces their ideas about mechanical engineering design. However, converting this idea to say a bin-packing problem would be a disaster. Most students do not have a pre-existing understanding of industrial engineering principles that can simply be fortified through outreach.

Previous works have combined industrial engineering concepts, such as the System Decision Process and the Analytical Hierarchy Process, to select a project for a particular outreach event, but it lacks a methodology to create new ones.[2] The authors use previously developed projects and the feedback from experts to select the best project. Jeffers et. al.[3] discuss many kinds of engineering outreach, including effective classroom practices, but also do not provide a methodology for the development of new activities.

The intention of this paper is to present a framework for adapting in-class assignments for outreach. After introducing the framework, three activities that have already been used for outreach and exhibit different levels of required adaptation will be explained. The first exercise introduces concepts relating to assembly lines and is based on a hands-on class assignment, so the adaptation is straightforward. The second exercise focuses on the development of a facility layout, and the adaptation involves changing the medium of the layout construction. The third activity uses Legos to introduce students to optimization and is adapted from a topic instead of a specific lesson plan. Each of these projects can be modified to suit various age groups, audiences, and time limits.

2. Framework

Tackling the invention of an outreach event can seem daunting. Younger students are painfully honest, and it is important to foster and maintain a good reputation with the community for high-quality, effective recruiting. Professors and students have a great source of inspiration for K-12 activities: the classroom.

Adapting college-level lessons for use with younger students requires an understanding of the objective of the exercise and the capabilities of the audience. The following framework, based on the development and implementation of many outreach projects, outlines a simple methodology for activity adaptation.

1. Identify outreach details
2. Select the topic or lesson for adaptation
3. Decide what concepts to include
4. Determine the most effective teaching methodologies
5. Make the chosen method interactive

a. Identifying Outreach Details

Many details of the recruiting event are key factors in the development process, including the outcome goals, location, time frame, event budget, and student age range. The outcome goals can be dictated by you or by the organization depending on the purpose of the project. In-school outreach events are often intended to tie into current course topics or demonstrate relevant applications. Common core and the new science standards require teachers to stay within the developed frameworks for their classes.[4] It is also important to recognize that goals often vary by grade level and teacher. For example, a fourth grade science teacher may want to expose students to engineering and the opportunities in engineering. If this teacher is also a gifted and talented teacher, it might be desirable for the activity to focus on the development of the students' problem solving ability. On-campus recruiting events are aimed at introducing students to the engineering disciplines and encouraging them to pursue engineering careers. It is ultimately important to ensure that the planned activity appropriately addresses the outcome goals, whatever they may be.

The location of the event is important for a couple of reasons. First, the planned activity must be doable in the provided venue, meaning not too messy, doesn't require more space than available, and won't disrupt anything in the surrounding area. An important part of this is the actual setup of the space. For example, a hands-on activity that requires the students to work in groups can be difficult to facilitate in a classroom with stadium-style seating. A flat room with lots of space would be easier to use in this situation. Reserving activity space can be difficult for on-campus activities depending upon classroom availability, and the space available may ultimately dictate certain aspects of the project. In addition, think about the amount of supplies that are required for the activity, ensuring that all materials are either brought or provided by the site.

The time frame can also affect the project that is chosen. Some well-designed activities are easy to fit into a wide range of available times, but almost all have some minimum and maximum amount of time required. It is as important to fit all the activity into the time available as it is to have enough planned to not leave dead time since students can rile up quickly when given too much free time. It should also be noted that students can and will surprise you. An activity that you think will take a group of 6^{th} graders an hour to do, might only take 30 minutes. This depends upon the skill level of the students. If it is the first time an activity is being performed, one should test the project and ultimately be prepared to cut material or facilitate additional content.

Perhaps the single most important thing to consider when developing a new outreach activity is the age group of the audience. This is primarily because the results can be disastrous if the target level is either too high or too low. If the activity is too basic then the students will become bored and eventually disruptive; however, planning a project that surpasses the abilities of the students results in frustration on both sides. This situation is particularly damaging because it furthers the stereotype that engineering is difficult and unattainable. Both scenarios can also be damaging to the relationships formed with host organizations. The experience needs to be valuable in order to be considered for future inclusion.

To further complicate this difficult balancing act, the results of outreach activities is often unpredictable. One activity can be performed many times with thousands of students and have a wide range of outcomes. These outcomes often fit a bell curve, with some groups performing extremely well or very poorly and the majority falling somewhere in between. This requires flexibility in implementation. Some projects are better suited to be scaled up in difficulty to suit the group, while others require simplification. For example, physical building projects are easier to simplify by removing constraints when students show signs of frustration. Math-based exercises, however, work better when the initial activity is on the easy side, but additional, more difficult problems are prepared in case students finish quicker than expected.

b. Selecting the topic or lesson for adaptation

Adaptation to outreach activities is most straightforward for in-class activities that are already interactive and fun for students. Activity 1, presented in Section 3, is this type of project. The next option is to select a lesson that is not currently interactive, but has some portion that can be made into a hands-on activity. Activity 2, presented in Section 4, is developed in this way. The final and least obvious type of project adaptation is based on a course topic that does not have a creative assignment already. Activity 3, presented in Section 5, is an outreach activity based on a broad course topic.

In addition to the ease of adaptation, the selected topic must be able to be simplified down to the appropriate level. For industrial engineering, it is also helpful when other basic principles can be incorporated in order to demonstrate as many facets of the discipline as possible. This step is also a great opportunity to incorporate K-12 topics that are currently relevant to your target student group.

c. Deciding what concepts to include

A college level lesson includes more depth and detail than is appropriate for K-12 students. Before the exact methodologies can be developed, the topic must be edited down to its critical components. Again, a balancing act must be performed that ensures that the resulting activity is not too easy or too difficult for the target audience. This is also a good opportunity to determine whether other, related industrial engineering concepts can easily be incorporated. Economic comparison, for example, is often easy to combine with other topics by adding monetary values to supplies and letting students "purchase" their desired materials.

d. Determining the most effective teaching methodologies

There are a variety of options available for leading an outreach activity, including presentation, project, demonstration, and discussion. Some kind of presentation explaining basic information that is applied in other parts of the activity is almost always required. This presentation should give students as much information as they need without going into too much depth and detail. Beyond the presentation, the methodology should fit the topic being taught. The activities in this paper all involve the development of a project.

It is very easy to end up speaking to a group of very lost students if jargon is not explained. Many academics have a difficult time remembering which part of their vocabulary is common knowledge and which is jargon. It is better to be safe than sorry in this instance. Explain any concepts you are not completely sure the students in the room will understand and eliminate all acronyms.

e. Making the chosen method interactive

K-12 students enjoy interactive exercises, particularly with hands-on tasks and, most importantly, competition. Keeping students engaged for the introductory phase of an activity can sometimes be challenging, but a well-structured interactive project is significantly more likely to hold student interest. In addition, nothing sparks an interest in engineering problem solving like an open-ended project that allows each student to develop a unique solution methodology, and nothing encourages students to do their best better than competition. It is also easier to hold the attention of students by using prizes to encourage initial involvement, activity participation, and hard work. These prizes can be anything; even candy. This is an especially convenient opportunity to further promote your university or company by providing shirts or other branded memorabilia.

3. Exercise 1 – Assembly Line

The first example of the introduced framework was utilized in a freshman-level introductory industrial engineering course in order to introduce the concepts of line balancing and quality control. The in-class activity is very interactive which made it a perfect candidate for translation to an outreach activity.

a. In-class Activity

Students were broken into groups and provided with the specifications for a product. The product itself is unimportant as long as it is made of readily available materials with enough specifications that it is not trivial to fabricate a product that conforms to all quality guidelines. The product in this exercise was layers of construction paper with precisely-specified dimensions onto which line segments were drawn and stickers were adhered according to strict quality guidelines. Each product was given a serial number according to the date and order of production.

Student teams were required to build a prototype and document required tasks. Each team selected six students to serve on their assembly line, dividing up the required production tasks, and constructed a learning curve by timing the fabrication of ten products. Students applied the results of the learning study to train assembly line workers and develop time standards for each task. Through experimentation, the teams balanced their assembly lines and predicted the number of quality products that could be made in 20 minutes. Teams also trained an inspector, an expert on quality standards, in order to prepare for an in-class competition.

During the competition, each team made products for 20 minutes. Each inspector was assigned to inspect and disqualify products produced by another team. The inspectors worked during the 20-minute production period and for 5 minutes afterward. Teams were evaluated based on the number of non-disqualified products produced and the quality of their prediction.

b. Development Process

While parts of the initial in-class activity were well suited for use in an outreach context, the scope of the project had to be significantly scaled back in order to translate it effectively, cutting a weeklong group project down to an hour-long kid-friendly activity. This project was selected for an hour-long portion of the industrial engineering section of the Explore Engineering Program 1 and 2, a weeklong half-day summer camp aimed to expose middle and high school students to the various engineering disciplines at the University of Arkansas. The facilitator wanted to ensure that multiple industrial engineering concepts were covered over the three hour time period; therefore, this project was designed to last one hour.

The inclusion of time studies, learning curves, and extensive line training are appropriate for a college-level audience, but go beyond the scope of an hour-long outreach activity. For this reason, the project was simplified to focus on assembly line design through experimentation and the importance of quality control.

Since the project was already an interactive and well-designed assignment, the adaptation was straightforward. The same teaching method used for the college age group was selected for use in the outreach event. This prevented the need to develop additional materials. Instead, the assignment was streamlined to focus on the selected topics.

c. Outreach Activity

Students worked in groups to develop an assembly line and then participated in a contest to determine which team could produce the most quality products in a given amount of time. The product itself again is unimportant and is a great opportunity to utilize available or leftover materials from other projects.

For our activity, the product was a boat made of disposable hotdog trays, straws, and construction paper. The only required tools were staplers for construction and rulers for inspection. The base of the product was a hot dog tray. Half of a straw was stapled to the bottom of the tray using two staples. Another straw was fed through that straw, bent in half, and stapled together at the ends, forming the mast of the boat. A rectangular flag was cut from construction paper and stapled to the top of the mast. Quality guidelines dictated that flags must be 1 inch by 2 inches with 1/16 inch tolerance, the center straw must not be within 3/8 inch of the side tray creases, both bottom staples must be flat side up, ends of the mast straw must be with 1/8 inch of the same height, masts must be at least 3 3/8 inch tall, and no extra holes could be present in the tray, flag, or straws.

We began by explaining the product to the students, including quality guidelines. They were given approximately 30 minutes to plan their assembly line and train a quality control specialist. When the time was up, teams swapped quality control specialists and the competition began.

The competition production time was varied between 10 and 20 minutes depending on the age of the students. Inspectors were allowed an additional 2 minutes to disqualify products. The team with the most quality items at the end of the competition period was declared the winner.

d. Recommendations and Future Work

If you utilize this activity, keep an eye on the inspectors to make sure they are not cheating. This activity is easy to implement because it requires no specific materials and is appropriate for a wide age range of students because it does not require calculations. It was facilitated with middle school and high school students by simply varying the time length of the competition and the amount of helpful suggestions provided during the planning phase. It was a very popular activity with both age groups.

4. Exercise 2 – Facility Layout

This exercise originated in a sophomore-level introductory level industrial engineering course and was used to introduce the concept of facility layout and layout efficiency. The in-class activity deliverable includes a graphic that can easily be translated to a hands-on physical representation of the final facility layout.

a. In-class Activity

Students served as consultants for a fictitious company seeking help in determining the layout of a new office facility. The office facility included 14 departments. The activity relationships between those departments as well as required square footages for each department and the dimensions of the building were provided to the students. Students were required to propose a single layout for the facility in a PowerPoint presentation that included a scale drawing of the proposed layout, a calculation of the layout's efficiency, the thought process behind their proposed layout, and critique of the proposed layout.

b. Development Process

The scope and scale of the layout development piece of the initial facility layout assignment was appropriate for use in outreach events, but the computer portion needed to be adapted to a more student-friendly, interactive medium. This project was also used as an hour-long portion of the industrial engineering section of the Explore Engineering Program 1 and 2 at the University of Arkansas. This project was designed to last one hour in order to accommodate multiple projects in the three hour time period.

The topics covered in the in-class assignment, including developing an effective layout and calculating the efficiency of a given layout, are appropriate for middle and high school students. The primary adaptation for this assignment was in implementation rather than content. The initial project involved drawing the final layout in a PowerPoint presentation. This is beyond the scope of an outreach project due to time, so the layout creation was turned into a hands-on activity.

c. Outreach Activity

Students constructed a layout for a new fast food restaurant, adhering to square footage requirements and maximizing layout efficiency and effectiveness. This activity requires more background explanation than the assembly line project, so the students were first presented with a short presentation about layout planning with particular emphasis on calculating a layout's efficiency.

They were then given the activity relationship and square footage requirements for 9 departments required in a fast food restaurant. The total square footage of the departments was exactly equal to the footprint of the building. Students were given a cardboard cutout of the building dimensions with a one-centimeter to one-foot scale. They were also given construction paper to cut out individual departments and adhere to the cardboard layout. It was helpful, though not necessary, to provide 9 colors of construction paper, one for each of the required departments in order for the students to easily compare layouts. Throughout planning and final layout development, the students calculated the efficiency of the current layout in order to determine the best final layout. The student with the highest layout efficiency with a reasonable layout was declared the winner.

d. Recommendations and Future Work

This activity requires minimal supplies and can be easily adapted to take as much time as available by manipulating the number of departments and the amount of free space available in the building. While this activity was performed with both middle and high school students, we found that many of the younger students were not ready for the square footage and efficiency calculations and became frustrated with that aspect of the activity, especially when they felt that other students were leaving them behind. It would be beneficial in future implementations to go over calculating square footage in more depth for younger age groups and make sure enough helpers are circulating through the room in order to help students calculate efficiency. A simple excel program could also be made to do the calculations for younger age groups.

5. Exercise 3 – Optimization

This lesson is a basic concept in any operations research course. The outreach activity is rooted in this industrial engineering concept, without being based on a specific course assignment.

a. In-class Activity

Mathematical modeling is a primary building block of operations research, and formulating linear programming problems is the most introductory topic in this area. In addition, the first method utilized to solve small linear programming problems is typically graphical. A common introductory optimization problem involves a company making tables and chairs each consuming some number of large and small pieces and producing some amount of profit. The formulation and graphical solution to this linear programming problem is the basis for this outreach activity.

b. Development Process

This activity required more adaptation than the previous exercises due to the lack of an initial creative course assignment. This project was implemented in a high school algebra classroom and had to fit in the 90-minute class period. This activity was used in conjunction with studying graphing inequalities. The hope of the exercise was to give students an example application for their current topic of study in hopes of eliminating the “when are we ever going to use this?” question.

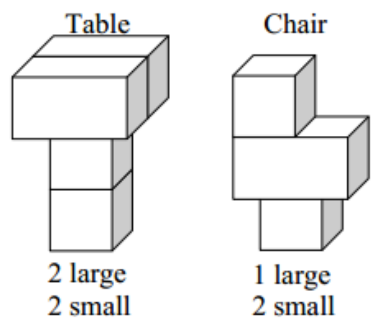
A physical experiment was chosen in order to make the problem interactive and aid student understanding. It was only appropriate to discuss formulating and graphically solving linear programming models, the topics selected for instruction, as a group, but the students were able to answer questions through individual experimentation.

c. Outreach Activity

This activity is based on a problem presented in the Mindset Project[1] linear programming chapter. It presents a problem that is easy to understand, building tables and chairs, and incorporates a hands-on approach to solving the problem using Legos.

The students were divided into small groups and given identical boxes of Legos, including both large and small pieces. A card was given to them with the following problem statement.

> *Consider a furniture company that makes two products: tables and chairs. Each table requires two large pieces and two small pieces, and each chair requires one large piece and two small pieces. The products are assembled as shown.*



> *The profit from each table is $16 and the profit from each chair is $10. If the company has 12 large pieces and 16 small pieces available, how many tables and chairs should be produced to maximize profit?*

The students were then given time to work through this problem and come up with an answer. As a group, we worked to formulate the problem as a linear program, graph the constraints, and determine the optimal solution. After this methodology was explained, students were asked how reducing or increasing the profit of a table changes the solution and allowed to answer by using Legos or analyzing graphically. Finally a manufacturing time constraint was added that eliminated the previous optimal solution and students worked in groups to determine the new solution.

d. Recommendations and Future Work

It would be easy to mimic this activity with any building materials that were easily available, but it is important to aim an activity like this at an appropriate audience that can follow this amount of material in a short period of time. In future, it would be interesting to complicate the problem by asking the student to solve the original problem with progressively more and more Legos. This would physically demonstrate how quickly this type of problem can become unmanageable in order to motivate the graphical solution method.

6. Conclusion

This paper introduces a framework for adapting in-class activities to K-12 outreach. This process includes analysis of the details of the event, the topic under discussion, the methodologies used to present the information, and the medium used to get the students actively involved. We presented three activities that have already been adapted and implemented, one at each of three levels. The first activity is a straightforward adaptation of an interactive lesson plan. The second activity required converting assignment deliverables into a hands-on project. The third activity was rooted in a broader topic, and the outreach project was developed from scratch. In future, it would be helpful to collect data measuring the effectiveness of each individual outreach activity.

7. Future Work

This framework was developed using expert knowledge and previous experience, but lacks additional validation. In future, the framework should be validated using standard methods, including student and teacher surveys focusing on the effectiveness of each project. It is important that validation efforts focus on the appropriate perspective of activity effectiveness. An outreach event is successful if the student had fun and learned something. It is particularly successful if it achieves the goal of the event as defined by the hosting school or organization.

Validation through implementation by others willing to test, improve, and provide feedback on the framework would also be beneficial. A key benefit of this widespread implementation would be the development of a larger pool of industrial engineering projects that could be shared and perfected by many outreach organizations.

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