BOARD # 210: Pack for Space: Development of an Engineering Outreach Activity on Optimization (Work in Progress)

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Abstract: Activities to promote engineering engagement can be costly to implement. Developing low-cost, low barrier engineering outreach activities can broaden access. This paper describes the development of a low-cost engineering outreach activity on the topics of optimization and human space flight. The activity discussed in this research is a pilot to enable refinement for larger-scale implementation.

The activity can be completed in 45 minutes and is targeted at 3rd-6th grade students. The students are told they will be responsible for determining what to "pack" for astronauts for a trip to the moon. The students must decide which items to pack and which to leave behind to make the "best" packing list. They are provided with a fixed size paper "cargo bay" made of discrete squares and paper items of various "lengths" in squares and values. The optimum solution can be achieved by dividing the value for an item by its length of squares and filling the cargo bay with the highest value/length items. Students not able to perform this level of arithmetic can also approach the problem by reasoning through which items may be the most useful for the mission. Practical items such as fuel are provided along with impractical items such as rubber ducks.

The students are provided an independent opportunity to solve the problem with no restrictions on the problem solving method. The first part of the activity introduces students to the concept of optimization and how optimization tools are needed in real world engineering problems. The solution is revealed and students can adjust their cargo bays. In the second half of the activity, students are asked to pack the "worst" list in the cargo bay. The activity introduces the concept of constraints and assumptions when the solution to the "worst", or lowest value, packing list is revealed to be packing nothing at all. The students are then provided the solution to the "worst" packing list with the constraint that the cargo bay must have all spaces filled.

The activity, titled "Pack for Space" was piloted with a group of 4 graduate students in 2022 and then conducted between 2022-2024 with groups of 15 - 20 elementary students at the annual Girls in Science and Engineering Days hosted at The University of Alabama in Huntsville. A cost estimate for running the activity, materials, and a guide to repeating the activity is provided for teachers and practitioners. This paper explores the development of the "Pack for Space" activity.

Introduction

Engineering outreach activities seek to increase interest in engineering as a future career [1]. Outreach activities outside of school have been shown to be effective in increasing engagement in Science, Technology, Engineering, and Math (STEM) [2]. Outreach activities are important as not all schools have access to STEM coursework and after school STEM programs have been shown to be more expensive than non-STEM programs [3]. STEM outreach involves and impacts many different groups including the students themselves, administrators, outreach providers, parents and guardians, universities, K-12 schools, government entities involved in STEM, industries, professional organizations [4]. This research discusses the development of low-cost engineering outreach pilot activity for Alabama students 3rd-6th grade to enable refinement for larger-scale implementation.

Many engineering outreach activities are available for use in Alabama, developed by organizations including the National Aeronautics and Space Administration's Office of STEM

Engagement, Alabama State Department of Education's Alabama Math, Science, and Technology Initiative (AMSTI), multiple universities, and private companies. This activity adds to the available activities by providing a low-cost engineering outreach that can supplement existing outreach. Some engineering outreach activities can be costly, requiring specialized materials or travel. Many organizations do not have excess funding for costly outreach activities. Developing low-cost engineering outreach activities enables greater access and increases the number of activities that organizations can host. Low-cost STEM outreach has been a focus of prior activity and program development (see [5], [6], [7], [8] for examples).

This activity, Pack for Space Activity (PSA), introduces the concept of constraints which are discussed in the AMSTI Engineering Guide as "limitations to the design" [9]. The constraints in this activity limit how many items can be included in the packing list. This activity also explicitly introduces the concept of optimization, which may implicitly appear in many other STEM outreach activities but is typically introduced for older students, potentially even in college level courses. PSA can be considered both an engineering and mathematics outreach activity (see [10] for an overview of STEM outreach content). We were only able to identify one additional engineering outreach activity that is focused on optimization, though it is likely more exist given the quantity of different outreach developers.

While PSA was not based on a previous activity, the authors have identified a similar outreach developed at NASA called "Priority Packing for the Moon" (PPM) [11]. The PPM activity differs from the described PSA in length (45-90 minutes vs 45 minutes), targeted age (5th-8th grade vs 3rd-6th), and required knowledge for students. The PPM activity requires the students to be able to evaluate the importance of objects based on human needs while PSA relies on numerical calculations of value, supplemented the students' perceptions of the importance of the objects. Both activities have similar lists of objects to those that appear in a "Ranking Survival Objects for the Moon" exercise [12] which is a group decision making exercise [13] but the PSA adds additional unexpected items to teach about different objectives in optimization and to engage the students. The PPM activity should be applied for older students (5th-8th grade) with longer activity durations while the PSA described in this research is targeted at younger students (3rd - 6th grade) in a 45 minute session.

While many engineering outreach activities exist, including low-cost activities, new activities can increase the variety of options available for outreach. This paper describes the development of a low-cost engineering outreach activity given between 2022-2024 to elementary students. A cost estimate as of 2024 for running the workshop and guide to repeating the workshop is provided.

Methods

Workshop Topic: Optimization

Good decision-making is a core concept in STEM education. In engineering, decision-making is most relevant in design courses, in industrial and systems engineering programs, and in operations research courses. Typically, the first step in those courses is to introduce students to modeling problems [14], [15]. This is a critical step that is often overlooked in K-12 education, and many times in undergraduate education. Often the tools to solve the problem are taught, skipping the critical step of formulating the problem. In engineering practice, challenges often arise due to misrepresenting the problem, rather than the actual process of making a decision.

Activity Learning Objectives
This activity, PSA, introduces two topics: optimization and space exploration. To best achieve the learning outcomes, students 1) would understand humans have participated in space exploration and 2) be able to perform arithmetic. The results section presents modifications for the activity for students who have not mastered these skills before the activity. The activity is designed to be modified for students who are not confident in arithmetic. After participating in this activity, students should be able to:

1. Describe optimization as "finding the best or worst"
2. Explain that optimization can be unconstrained or constrained
3. Explain there may be multiple optimums or two solutions may both be the "best"

Since optimization is often described in complex terms, we expect students to understand and describe the concepts in simple language presented in the activity. Optimization is described as "finding the best" or "finding the worst". The activity begins with the simple constraint that the size of the cargo bay can not be exceeded. In the second part of the activity, students will often apply the inverse constraint that the entire cargo bay must be filled, which leads to an incorrect solution to illustrate the difference between constrained or unconstrained optimization. The activity is also designed to have two optimums. The activity should build confidence in arithmetic and encourages open-ended problem solving without directing students on how to solve the activity.

Activity Flow
Preparation and Materials. Before the activity, poster board was cut to the size of 30 "squares", equivalent in size to the squares shown in dotted lines within each item in Figure 2 to serve as the cargo bay. The cargo bay is shown in Figure 1 (not to scale with Figures 2-5). Additional materials include calculators, paper, and pencils.

Figure 1. Cargo Bay (Not to Scale).

The complete candidate packing list is shown in Figure 2. Figure 2 can be printed once per participant or group. Alternatively, each item can be printed on different colored paper.

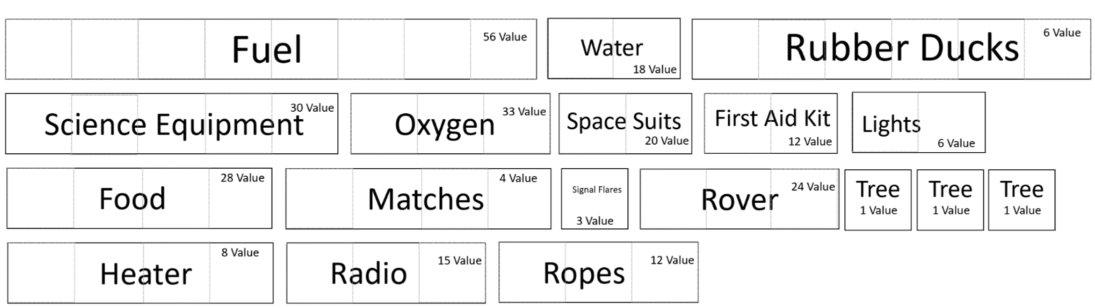

Figure 2. Complete Candidate Packing List.

Activity Solutions
The three solutions are shown in Figures 3-5. The optimum solutions shown in Figures 3 and 4 are based on choosing the highest value per square and then summing the sub-values for each item for a total value of 224. The optimum solution shown in Figure 5 is based on choosing the lowest value per square and then summing the sub-values for the items for a total value of 81. If different quantities of items are provided to the students then the optimum solution may change. For example, as shown in Figure 2, three trees are provided as candidates.

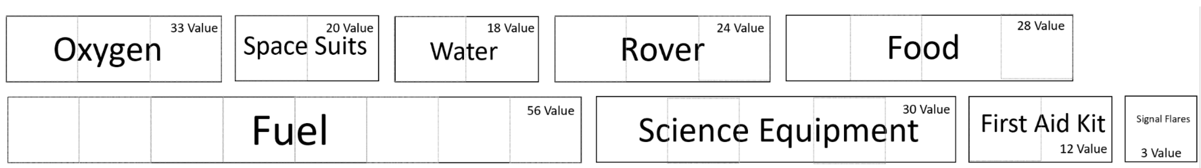

Figure 3. Optimum or "Best" Packing List Solution 1.

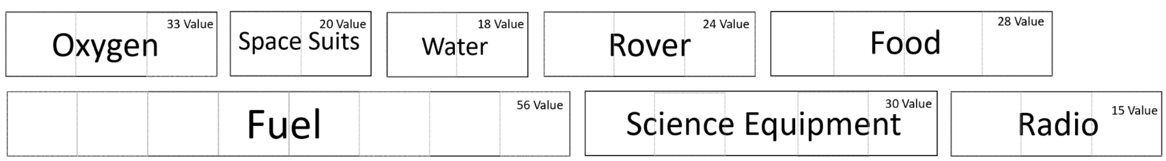

Figure 4. Optimum or "Best" Packing List Solution 2.

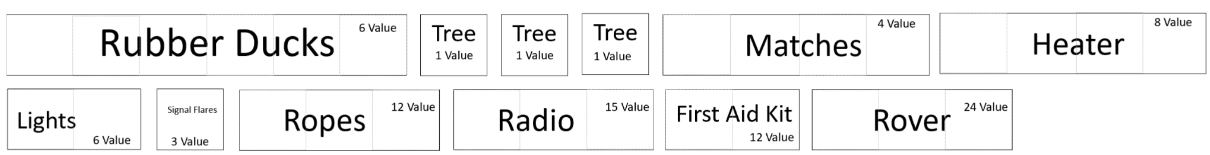

Figure 5. Optimum or "Worst" Packing List Solution with Filled Cargo Bay Constraint.

Framing. First, students are asked "What is optimization?". Then after a brief explanation and discussion, the activity begins with framing space travel to a familiar activity of packing for a trip or packing to move. Students are told they can only pack a certain amount or it will not fit. A cargo bay can be compared to a car trunk or a suitcase. The framing should be completed within the first 10 minutes.

Introducing the Part One Optimization Problem. Two attributes for the optimization problem should be introduced: 1) the size of the cargo bay and 2) the value of items. Value can be introduced as the "goodness" of an item. The size of the cargo bay is represented with a limited number of spaces. The physical items are cut to predetermined lengths.

The students are instructed to pack the "best" list in groups, explained as the most value or the highest number for the entire list. The students are given time to solve the activity. After they appear to finish, the students are asked what value their packing list has.

Revealing the Solution for Part One. Once all students have calculated the value of their packing list, the solution can be revealed. One solution of the optimum packing list and the value should be shown. Identify if any students got the same packing list and value. Identify if any student got the same value with a different solution. Reveal there were two equally good solutions. Have students match their packing list to either solution. The solution should be revealed around the thirty minute mark for a 45 minute activity.

Introducing the Part Two Optimization Problem. Tell students they now need to pack the "worst" list. Repeat the process described in part one.

Revealing the Solution for Part Two. Once all students have calculated the value of their packing list, the solution for part two can be revealed, that packing nothing provides the lowest value of zero. The students should be told that you never said they had to pack anything at all.

Since students often will fill the entire cargo bay, tell the students to now pack the "worst" list if they have to fill the whole cargo bay. After they appear to finish, the students are asked what value their packing list has. Identify who achieved the lowest value.

Once all students have calculated the value of their packing list, the solution can be revealed. Identify if any students got the same packing list and value. Have students match their packing list to the solution.

Activity Reflection. After completion of the activity, students were asked what optimization was and given an opportunity to share their thoughts. The activity reflection can be shortened or lengthened to fill the remaining time for the 45 minute time slot depending on how quickly the students complete the activity.

Results and Discussion

Pilot Testing

The activity was pilot tested with graduate students and the target audience of 3rd-6th grade students. The activity was pilot tested with four graduate students at The University of Alabama in Huntsville to identify any errors and confirm the correct solutions were able to be identified.

The activity was also pilot tested for 7 sessions between 2022 and 2024 at the Girls in Science and Engineering Days (GSED) at The University of Alabama in Huntsville. 15-20 students participated in each session, for a total of over 100 students. Each session was forty-five minutes long. The students ranged from 3rd -6th grade.

Expected Problem Solving Approaches

Three problem solving approaches are expected from 3rd-6th grade students. First, it is expected that some participants will be able to mathematically solve the activity by finding the highest value per square and filling the cargo bay by decreasing value per square. We expect some participants will have the skills to use mental math, calculators, or perform arithmetic on scratch paper.

Second, it is expected some participants will not identify value per square as the ideal problem solving approach. These participants are expected to take the highest overall value per item, regardless of value per square. It is expected that participants will fill the cargo bay starting with the highest value per item followed by decreasing value per item.

Third, some participants are expected to solve the activity just through the item names and the participants' assessment of their utility. The numerical value of the items by design is associated with the items' practicality for the scenario of space travel. Some items like rubber ducks can be excluded immediately by participants as incorrect.

Cost Analysis

Estimated costs to set up the activity for a session of 20 participants from scratch are shown in Table 1. The total cost to begin is $51.81 priced in 2024 in the state of Alabama. For the GSED workshops, calculators were borrowed from a summer camp program, reducing the total cost for all 7 sessions to $24.82. The cost per participant in the 7 GSED sessions to date is estimated to be below $0.20. Repeated sessions will further reduce the costs as all materials are reusable unless damaged. Laminating the materials can reduce the risk of damages.

Table 1. Initial Set Up Costs for Session of 20 Participants as of 2024 Local Pricing.

Item	Quantity	Cost
Poster Board 22" x 28" at $1.00 per board	2 boards	$2.00
Paper 8.5" x 11" at $3.99 per 500 sheets	20 sheets	$3.99
Cardstock 8.5" x 11" at $14.99 per 20 colors/200 sheets	16 sheets	$14.99
Printing at $0.24 per sheet	16 sheets	$3.84
Calculator at $25.99 for a 25 pack	20 calculators	$25.99
Pencils at $1.00 for a 24 pack	20 pencils	$1.00
Total Cost	$51.81	

Future Work

This research described the development of an engineering outreach pilot activity. Future trials will assess participant responses to the activity and document problem solving approaches observed by the participants. Both participants' perceptions on the activity and perceptions on engineering can be assessed. In future trials, pre-activity and post-activity surveys will assess the direct impact the activity had on student perceptions of engineering. Different age groups can also be trialed.

Acknowledgment

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