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STEM in a Shoebox

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Introduction

In the College of Engineering at Carnegie Mellon University, our faculty, staff and students are often asked to attend STEM events and visit schools to share STEM content with K-12 math and science classes. Requests are sometimes well in advance of the delivery date but can also be received at the last minute, with little time for adequate preparation. We are exploring a solution to this challenge that will serve to increase the participation of our STEM outreach volunteers and provide the recipients with a more complete STEM experience. The proposed solution is the advance preparation of stand-alone kits, complete with a scalable lesson plan, that will fit in a container with the approximate size of a 'shoebox' and will be stored and catalogued in the engineering and science library.

The original intent of the kit approach was to facilitate the College of Engineering's collective inclusion of more stakeholders at the university (the library and maker space, for instance). In addition, teachers in the local school districts have had valuable input and look forward to the collaborative creation of additional kits.

This paper is primarily about the process of creating a kit and scalable lesson plan that can be used for informal outreach as well as incorporated into larger broader impact initiatives. At Carnegie Mellon, this process has been developed by an interdisciplinary team from the College of Engineering, the Engineering and Science Library, the Engineering Research Accelerator, IDeATe (Integrative Design, Arts and Technology) Lab, and the Leonard Gelfand Center for Service Learning and Outreach.

Background

Our College of Engineering is committed to the promotion of STEM and our faculty, staff and students are very active in STEM outreach activities. Examples of annual activities include:

- Summer Engineering Experience for Girls
- Summer Center for Climate, Energy, and Environmental Decision Making
- Carnegie Science Center Events (including Girls Rock Science and Sci-Tech Days)
- Allegheny Intermediate Unit HS School Apprentice Program
- Engineers' Week events on campus and at the Carnegie Science Center

We believe that our effectiveness will improve if we can address some challenges. One challenge is the limited availability of hands-on activities that are readily available for transport to schools and other STEM related events, such as those at the Carnegie Science Center. The kit initiative, whereby the kits are stored and catalogued in the Engineering Science Library, is a potential solution to this problem. Second, it is often difficult for our faculty, staff and students to understand and therefore target the skill and knowledge level of the students that we intend to engage and enlighten. One potential solution to this second challenge is to prepare scalable lesson plans that can guide the presentation based on the grade level of the students. As an additional benefit, the lesson plan creation process has allowed the promotion of intentional dialogue and exchange with the students and educators that are the ultimate beneficiaries of the kits.

Literature Review

Learning is enhanced when the student is actively engaged in the process [1]. When reviewing possible activities for the STEM in a Shoebox kits the team sought to select activities that require students to practice behaviors including observation, experimentation, data collection, analysis, and iteration to improve their designs. This approach is aligned with the *Framework for Implementing Quality K-12 Engineering* which notes, "Engineers use a variety of techniques, skills, processes, and tools in their work. Students studying engineering at the K-12 level need to become familiar and proficient with some of these techniques, skills, processes, and tools" [2] The kits are designed to be used in different contexts, from short term demonstration experiences to activities which involve students in partial design challenges that require them to collaborate with their peers to solve a problem or answer a question. Recognizing that engineering has connections to science, mathematics and technology learning that is already taking place in schools [3], the instructional guides which accompany the kits include relevant vocabulary and background information enabling the presenter to connect the engineering activity to prior knowledge and to ensure that students are able to apply the correct terms within the context of the activity.

Even though various STEM educational resources and construction toys are available commercially, the distinct goal of our STEM in a Shoebox program is to offer enrichment with custom-made activities and support documents. A few similar programs were identified and reviewed to examine how these services were developed. We asked the following questions:

- What is the cost of a kit, particularly how much was spent on kit consumables?
- How did the program assess its success?
- Were some willing to share specifics about building their kits, including potential copyright issues?

At North Dakota's Grand Forks Public Library (GFPL), grant monies from IEEE and the ND State Library allowed for the purchase of materials for their STEM kits. Worth noting is that their STEM library activities are made possible through cooperation with the Dakota Science Center (module developers) and the University of North Dakota College of Engineering and Mines. The GFPL's model supports the creation of STEM modules for their STEM Kids programs held afterschool in the GFPL [4]. The modules incorporate typical elementary school lesson plans. The time needed for creating supporting documents to accompany STEM kits became an important consideration for this outreach effort. Each shoebox would include materials for the activity and consist of a description, related keywords and glossary, an outline of goals, as well as, lesson plans and student activity sheets for various grade levels.

The aim for our inaugural STEM in a Shoebox is to allow for the use of STEM kits outside of the University's physical library spaces. As similarly planned at Carnegie Mellon University, Mayville State University, North Dakota is an example of a program whose kits are available via the library's catalog. With an award from the Institute of Museum and Library Services, Mayville State University's Byrnes-Quanbeck Library also created a STEM kit collection reservation system, called Kitkeeper. The system allows area teachers to search by the kit's name or by STEM subject or grade level [5].

The STEM Lending Library at the West Tennessee STEM Hub offers a one-month loan period for teachers to borrow K'NEX kits. It is one example of higher education institutions partnering with industry and K-12 school systems to enrich STEM learning. In their STEM Hub Fact Sheet for 2016, they note: "92% of teachers report the STEM Lending Library materials increase interest in math, science, and engineering with their students." [6] Plans to assess the suitability of the kits at Carnegie Mellon include a kit user voluntary survey. Modifications to any kits may be made based on feedback received.

The STEM Kit Library at Colorado State University's Education & Outreach Center, College of Natural Sciences also loans to local teachers. Their production lab has the ability to customize kits, including downloadable brochures, use the fewest consumables possible, and incorporate math and science notebooks. They have a method in place to weekly test them with students at their STEM Friday program [7].

Carnegie Mellon is inspired by others with successful STEM kit programs and will create its own unique STEM kits. Some parts contained in "the shoebox" can be fabricated using available equipment at its IDeATe collaborative "makerspace" facility housed at the University's Hunt Library.

Project Description

In order to address the challenges noted above, our team agreed that:

- Hands-on activities are more effective in engaging K-12 students
- Participation at local outreach events can be limited by the
    - availability of hands-on activities
    - amount of time required to prepare for the event
- Outreach events can vary in length of time as well as grade level of the students

The proposed solution was the preparation of stand-alone and self-contained kits that would be stored and catalogued in the engineering library. The kit would include all of the necessary consumable and non-consumable components necessary to conduct the activity and/or demonstration. In addition, the kit would include a scalable lesson plan that could be optimized based on the available time as well as the grade level of the student participant. The kit and lesson plan might be used by one of our colleagues or may (eventually) be borrowed by a K-12 teacher.

Sources

Ideas for kits are readily available. Through the IdeATe lab and other rapid prototyping engineering classes, there is a collection of projects and ideas that are to be advanced through the development of a kit. Likewise, through our summer programs, broader impacts initiatives and other outreach events, we have a queue of activities that would be suited for kit creation.

Kit

The kit itself will contain components to be used for the implementing the activities. Those components might be consumables (that must be replenished after use) or non-consumables. And, to the extent possible, we intend to make the non-consumable components in our IDeATe lab or other maker space using laser cutting and 3D printing technology which will make it possible to produce many kits of the same type, say for an entire classroom activity, simply and economically. In the future, if there is interest, we may consider having the 'maker files' available for teachers so that they can ultimately build (3D print) their own kits, thus eliminating the need to borrow them. We chose the 'shoebox' dimension as a manageable size for ease of storage in the library as well as transport to off-campus events.

Lesson Plan

According to recommendations from the Committee on Integrated STEM Education (National Academy of Engineering and National Research Council of the National Academies), "Programs that prepare people to deliver integrated STEM instruction need to provide experiences that help these educators identify and make explicit to their students connections among the disciplines" [8]. The aim of the kits is to provide instructors with exactly this type of support by inclusion of specific learning goals, with the understanding that other unexpected learning may also be revealed.

Lesson plans have been thoughtfully and flexibly designed to accommodate different age levels as well as different durations for delivery of the activity. This framework for the lesson plan is shown in The Activity Overview, Table 1, a matrix where the target age groups are defined as Grades 4-6 (Aware), Grades 7-9 (Assess) and Grades 10-12 (Analyze) the activity time durations are estimated to be 10 minutes (Engage), 30 minutes (Explain) and 60 minutes (Evaluate.)

Ramp Racer Example

The Ramp Racer (fabricated from laser cut acrylic), originated as a student project in a rapid prototyping course. With this as the starting point, the campus collaborators (from the engineering department, outreach and the engineering library), began to meet and conceptualize the content of a *Ramp Racer* kit and lesson plan. The premise was to allow student participants to explore the concepts of gravity, speed, and momentum while beginning to understand the potential effects of variables such as mass, slope, and friction. Components of the kit include:

- Ramp and wall (with associated assembly pieces)
- Weights (pennies and dimes)
- 'Hot Wheels' trucks (4)
- Fabric
- Sandpaper
- Measuring tape
- Protractor
- Stopwatch
- Kitchen scale
- Pencils, erasers, rulers
- Data collection sheets and graph paper

Table 1: Activity Overview (example from the Ramp Racer kit)

Activity Overview – note that activities are additive (60 minute activity should be prefaced by the 10 and 30 minute activities) (Also, please See data collection sheets in Appendix.)

Grades\Time	**10 Minutes (Engage)**	**30 Minutes (Explain)**	**60 Minutes (Evaluate)**
4-6 (More details in Appendix …) *Be AWARE of ..*	Demonstrate the ramp and experiment with different features to produce different results. Talk about other examples where this information might be relevant to real world situations	Assemble the ramp and give short explanations about each feature (slope, truck and payload, material in the run-out length). Let the students experiment afterwards. Ask the students to write a sentence or 2 about their observations	Introduce concepts of physics and math. Experiment with the activity and collect data related to slope, weight, travel distance. Graph the data, use the graphs to make predictions, then test your predictions.
7-9 (More details in Appendix) *Be able to ASSESS …*	Ask students to make predictions then test their predictions and discuss the results based on the variables of slope, weight, and friction. Talk about other examples where this information might be relevant to real world situations	Have students assemble the ramp while explaining how it relates to the activity concepts. Map a strategy to test the different variables. Run each test; collect and graph the data. Ask the students to write a sentence or 2 about their observations	Have the students develop a hypothesis and develop the tests to prove their hypothesis. Graph the data, use the graphs to make predictions, then test your predictions.
10-12 (More details in Appendix) *Be able to ANALYZE ..*	Have the students assemble the ramp then determine the velocity of trucks while changing the variables of slope, weight, and friction (run-out materials). Discuss principles of physics, geometry and trigonometry. Talk about other examples where this information might be relevant to real world situations	Have students assemble the ramp while explaining how it relates to the activity concepts. Map a strategy to test the different variables. Run each test; collect and graph the data. Discuss how the kit might be modified to determine acceleration. Ask the students to write a sentence or 2 about their observations.	Have the students develop a hypothesis and develop the tests to prove their hypothesis, including force and acceleration. Graph the data, use the graphs to make predictions, then test your predictions.

The associated lesson plan (included as Attachment 1, and grade specific lesson plans in Appendices A, B and C)) is scalable both in terms of the target age group as well as the time available for the event. The Activity Overview for the Ramp Racer is presented above in Table 1. The age groups are defined as Grades 4-6 (Aware), Grades 7-9 (Assess) and Grades 10-12 (Analyze) the activity time durations are estimated to be 10 minutes (Engage), 30 minutes (Explain) and 60 minutes (Evaluate.) Data collection and graphing are also elements of the exercise, especially in the 'Evaluate' phase of the optional levels of immersion in the topic matter. Appendix D provides the student worksheet for data collection.

There is a general portion of the lesson plan that includes: abstract, key words, the Activity Overview, a paragraph about real world relevance, thoughts about how students might relate, material list, glossary, anticipated student questions, recommended readings, thoughts about 'what could possibly go wrong,' and safety suggestions. Appendices to the lesson plan include specific instructions for each grade level as well. In each section we support the teacher or presenter with a mapping relevant to the Next Generation Science Standards as well as provide a 'Connection to Engineering and Careers.' With regard to the latter, here is the paragraph created for the 4-6th grade instruction appendix:

> Engineers are often posed with a question or challenge, such as: which variables (slope, weight, friction) cause the truck to travel the farthest, the fastest, the shortest, or the slowest? To give a definitive answer, they will have to provide mathematical and scientific proof, but to get started, they might just run some simple experiments to get a basic understanding of the problem and the general effect of the variables. With a basic understanding and the ability to collect the supporting data, the engineer can then develop the mathematical equations (or proof) that will allow for the development of a reliable and replicable engineering solution.
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> To think like an engineer, one must be curious (what is the problem?), methodical (how can I parse the problem down into smaller, more management components?), objective (is there more than one way to solve the problem?), analytical (what are the principles of math and science that allow us to define the problem and the solution?), and practical (what is the most cost effective and reliable way to solve the problem?) This exercise allows us to explore some of the traits of an engineer.
>
> Specifically, civil and mechanical engineers might be inclined to use the principles of math and physics that are explored in this exercise.

Kit Maintenance and Storage

The library is a natural outreach partner to the STEM community with a goal to provide materials to enrich all of the university constituents from faculty and staff to our students of all levels – and to include our local community of educators' K through 12. The Engineering and Science Library will assist with the collection of kits from their inception by cataloguing each item, maintaining the supply levels in each as they are vended and returned, and to promote and advertise their use and availability. The Engineering and Science Library at Carnegie Mellon University is committed to the goal of "Impacting society in a transformative way – regionally, nationally, and globally – by engaging with partners outside the traditional borders of the university campus." This unique partnership is a model that provides the College of Engineering with management system for lending of the kits and provides the Engineering and Science Library with a creative opportunity to meet their intended goal of expanded engagement.

Next Generation Science Standards

In addition to developing a lesson plan that can guide users of the kit, this team also chose to assist the classroom teachers in helping to define the relevance to their math or science class. We chose the Next Generation Science Standards as our guide. The mapping of the NGSS on to the activities of the kit might not be direct, but it provides a useful guideline for the teachers and therefore provides encouragement for adoption of the kit. Please see the appendices in the draft lesson plan for an example of the identification of standards relevant to the targeted grades.

Beta Testing

The version of the Ramp Racer lesson plan discussed in this paper is the result of 2 focus sessions with middle school teachers. In addition, we have taken the Ramp Racer kits to science fairs as well as into 2 middle school classrooms. At a science fair, time (and attention spans) are limited, so the Ramp Racer activity will allow for the exploration of 1 or 2 variables. Science fair events have been manned by faculty or staff but by undergraduate students as well.
Undergraduate students have not only made construction suggestions to improve the Ramp Racer kit but have also become secondary beneficiaries of the experience. At science fair events, children of a variety of ages will stop by, often in groups and sometimes with a parent or teacher. The individual performing the demonstration will have to gauge both the content and length of the demonstration because distractions will dictate the attention level of the visitor.

The classroom, with teacher participation, provides some different observations. When first provided with the lesson plan, the teachers have rewritten and adapted it to be consistent with the flow of their respective classes and the learning level of their students. Second, the kit requires a limited number of tasks and therefore can only be used effectively with 4 or 5 students. One immediate take-away from the classroom experience is that the kit lends itself to a long program as opposed to a short program. When the teachers and students begin to engage with the kit, they can generate new variables to explore and or different ways to configure the physical components kit. We also recognized that the lesson plan and data collection sheets provide a framework, but the teachers will modify the materials based on his or her knowledge of their respective students.

Next Steps

The Ramp Racer is ready for use by those performing outreach at a science fair or in a classroom. We are in the process of identifying additional kits following the same format for the lesson plan. We imagine that the through the creation and beta testing of additional kits, we will continue to optimize the structure of the lesson plan.

In addition, we need to begin to develop metrics for the assessment of the effectiveness of the kits. Assessment data might include but is not limited to:

- Are teachers using the kits and for what grade levels?
- Are the kits complimenting their lesson plans?
- How many students have interacted with the kits?
- Are their students gaining a better understanding of the field of engineering through

the use of the kits?

- Are our faculty members, staff and students using the kits? How much activity is the Library managing with the kits lending program?

Data might be collected via student activity sheets, teacher observations, and surveys. Kit instructors will be asked to complete when finished using the kits. Kits will be analyzed for modifications accordingly. Our future proposals to foundations as well as possible government and industry entities will be strengthened by: a better ‘track record’ of the effectiveness of the kits, the network that we are able to enhance with local K-12 teachers, and the ongoing meetings and discussion of the STEM Outreach Committee.

Conclusion

The methodology described for design and use of the Ramp Racer kit for a variety of student levels provides the framework for future kit development. We have received a grant from Carnegie Mellon to develop more kits about a range of engineering and science topics to include: forensic science, construction of a tiny house, lemon based batteries and electrical energy conversion. Additional topics will be generated from faculty and student research interests as well as the rapid prototyping class in the IDeATe Lab. We will work toward obtaining future funding sources from government, foundations and industrial sources to grow the repository of kits.

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