

Design-based research project to develop a science and engineering education program linking field trip experiences to classroom experience

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The Next Generation Science Standards have incorporated engineering standards, requiring K-12 teachers to teach engineering. Unfortunately, teachers are ill-prepared and have little comfort to introduce these unfamiliar complex topics into their classrooms. The University of California at Santa Barbara and MOXI, The Wolf Museum of Exploration + Innovation partnered up to tackle this problem and bring physics-related engineering activities to teachers through the MOXI Engineering Explorations program. A key challenge has been creating activities so that they are effective learning opportunities for first graders (6 years old) through sixth graders (12 years old). Here, we present design guidelines for adapting activities for younger and older children. This framework is also useful for other physics outreach programs that work with wide a range of age levels.

I. INTRODUCTION

There is evidence that early interest in STEM (Science, Technology, Engineering, and Math) is a significant predictor of students pursuit of physical science and engineering careers [1]. Yet, unfortunately many students get very little science instruction, especially physics and engineering, during these critical elementary and middle school years [2]. One reason for this is that elementary school teachers feel unprepared to teach physics and engineering. Additionally, new K-12 science standards, the Next Generation Science Standards(NGSS) [3], are currently being rolled out which shift the expectations towards instruction that focuses on learning science content through practices that align with science and engineering practices. These standards also include engineering at all levels from Kindergarten through High School, an area many elementary teachers lack experience with.

Outreach programs through university physics departments, science museums, and other "informal science environments" (a term used to refer to out-of-school learning environments) can share the responsibility of providing experiences for youth that help children develop engineering and physics ideas and skills while also increasing teachers' confidence in their capacity to integrate both engineering and physics into their instruction.

Ideally, outreach and field trip programs, provided by both physics departments and museums would complement the education that students receive in formal school settings and the curricular goals of districts and states [4]. Yet, these experiences are not often integrated into regular curriculum. We are working to change that through an integrated model of museum field trip programs focused on engineering and physics and coordinated classroom activities to prepare students before they attend the field trip and to help them reflect on and extend the learning in their classroom.

While these classroom activities will eventually be led by classroom teachers, we are testing them first as outreach programs led by university and museum staff with input and assistance from classroom teachers. The field trip and the classroom activities are implemented with students as young as 1st grade (6 years old) and as old as 6th grade (12 years old). Developing activities that are appropriate for a broad range of ages is challenging, but not unusual for outreach providers. This motivated the development of a set of principles to guide adaption of the activities so that the activities retained similar structure while also supporting students in developing skills and ideas that are age-appropriate. Through the process of iterative developing and testing activities at multiple grade levels, we identified components that can be adapted to make activities appropriate for different grade levels which is useful for teachers adapting physics activities for their grade level. As an example of how activities can be adapted, we present an example from one activity and how it was implemented across grade levels.

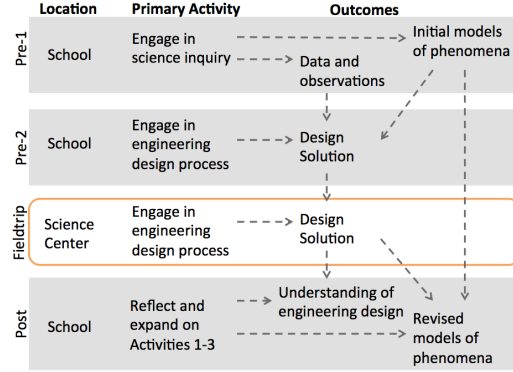


FIG. 1. Timeline of activities in an Engineering Explorations module. The three activities in rectangles are completed in an elementary classroom. The Activity in the oval is completed during a field trip to an interactive science center.

II. RESEARCH CONTEXT

Engineering Explorations is a three-year project with the goal of developing modules of coordinated classroom and field trip activities. Each module consists of an engineering design activity completed during a field trip to an interactive science center accompanied by two pre-activities done in students' classrooms before they come to the science center, and one post-activity completed in the classroom after the field trip. Each activity is designed to take 50 minutes. Activities done in classrooms use minimal or easy to access materials while the field trip activities leverage materials or exhibits available at the science center (see Fig. 1).

Here we focus on the first of four activities from one Engineering Exploration module. As shown in the figure, this first activity is a science inquiry with the intended outcomes of eliciting initial conceptual models of a science phenomenon and collecting data and observations. The first classroom activity helps students develop familiarity with materials and construction techniques.

The first *Engineering Explorations* module is built around a field trip activity in which students design a craft out of paper that will hover in a column of upwards-moving air while supporting the weight of a penny or small washer. The crafts are tested in an exhibit at the science center that includes a rising column of air and students iteratively revise their designs (See Figure 2). In order to tackle this design challenge, students needed to understand the idea of balanced forces (NGSS 3-PS2-1) and be able to identify the forces acting on the craft. In this case, the forces are the upward force of the air on the craft and the downward pull of the gravitational force of the Earth on the craft. They also had to understand that the upward force of air on the parachute increases with the surface area of the craft and the downward pull of the Earth is proportional to the mass of the craft. We created versions of this activity that developed those concepts appropriately for a range of grade levels. To prepare for this field

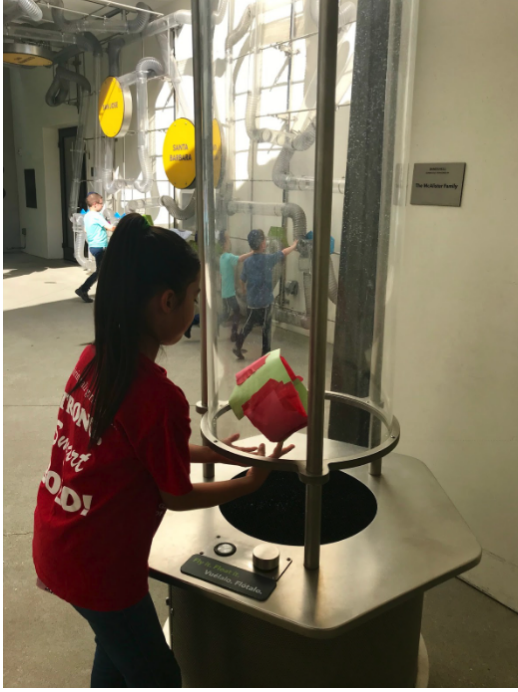


FIG. 2. Student on field trip program testing hovering craft

trip during the first classroom experiences, students built and tested parachutes. The parachute activity is more fully described in the results section.

III. RESEARCH METHODS

The work presented here is part of a larger project that follows a Design-Based Implementation Research (DBIR) approach [5] through an established Research-Practice Partnership [6] between museum practitioners and university faculty, and collaborating classroom teachers. Design based research is an iterative process that includes systematic inquiry to developing theory around school (or museum) learning and includes multiple stakeholders. DBIR further strives to understand the systems that build capacity for change.

To identify initial test sites, we reached out to all local school districts seeking school test sites who were interested in multiple classrooms participating. We identified two schools to test the program in year one. *School A* identified 40% of its students as English Language Learners with 62% of the students qualifying for free and reduced lunches. *School B* identified 9% of its students as English Language Learners with approximately 11% of the student population qualifying for free or reduced lunches. We also worked with an afterschool program that served girls in the local area. Table 1 depicts the number of classrooms that the module was tested with at each school. The Afterschool program actually had two classes, both of mixed 3rd and 4th graders. For ease of presentation, we represented this on the table as separate

grade levels.

TABLE I. Classrooms observed (number of student participants)

School	1 st	3 rd	4 th	6 th
School A	3 (n=33)	0	2 (n=46)	0
School B	0	3 (n=52)	0	2 (n=27)
Afterschool	0	2 (n=10)	2 (n=11)	0

We collected video recordings from nine of the ten classrooms we visited and both classes from the afterschool program, as well as student work from all classes and teacher interviews and surveys before and after the implementation of all four activities in the module.

In addition, activities from a different module was tested in a comparable number of classrooms and what we learned from the implementation of both modules informed the other. The data collected from each class was analyzed using Agar's frame class approach [7] to identify areas for improvement in subsequent iterations of the activity.

IV. RESULTS

For the activity focused on here, our goal was for students to develop skills to test design changes that they would use in subsequent engineering activities and also to develop an understanding about the forces that act on a falling parachute. However, between 1st and 6th grade, children learn valuable math and literacy skills and develop proficiency in engaging in the science and engineering practices described in the NGSS [8]. When we compared the changes we made to adapt the activity for multiple grades, we identified that our adaptations aligned with how students engaged in three NGSS practices: Planning and carrying out investigations (practice 3), Analyzing and interpreting data (practice 4), and Obtaining, evaluating, and communicating information (practice 8).

We created versions for three grade level bands (1-2, 3-4, and 5-6) to simplify our design process and implementation. Below we first describe the middle version and then how it was adapted for lower grades (1-2) and upper grades (5-6) using the three practices mentioned above (see Table 2).

A. Parachutes activity for third and fourth grade

We first present the activity as implemented with third grade students. In an initial ideas discussion, students brainstormed which aspects of a sample parachute could be changed (e.g., size of the canopy, length of strings, material, color), why they thought we should only change one variable in an investigation, and why it is important to conduct multiple trials. We then focused only on the canopy size. Students predicted which of the three parachutes would fall the slowest (see figure 3) by writing a sentence and discussing their ideas

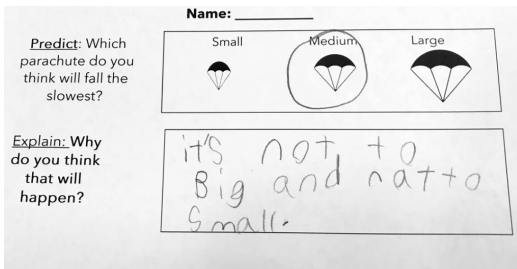


FIG. 3. Sample third-grade worksheet identifying the parachute they thought would fall slowest

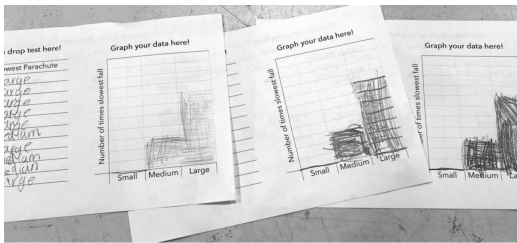


FIG. 4. Sample third-grade worksheets for data collection

with partners and the whole class (think-pair-share). While many students predicted the largest one would fall the slowest ("because it catches the most air"), some predicted that the smallest one would fall the slowest ("because it is the lightest") and some predicted that the medium one would fall slowest ("because it's not too big and not too small"). All predictions were valued and discussed.

In groups of three or four, students were then provided with pre-cut squares of tissue paper in three sizes that became parachute canopies. The students cut strings of the same length for their parachutes and constructed three parachutes. They then conducted 10 trials and recorded which of the three parachutes landed last each time (see Figure 4). Students shared their results and explanations of the parachute data verbally to the class. The facilitator held a whole class discussion with the goal of identifying trends in the data and solidifying an understanding of the key physics concepts. Most students noticed that the largest parachute fell the slowest for most of the trials. But they also noticed that sometimes one of the other parachutes reached the ground last. This provided the opportunity to discuss variation in data, why we make many trials, and being careful about measurements.

B. Adapting this activity for younger and older students using NGSS practices

1. Practice 3- Planning and Carrying out Investigations

Adaptation 1: Materials.

Students develop key motor skills during their formative elementary school years. The materials available to students

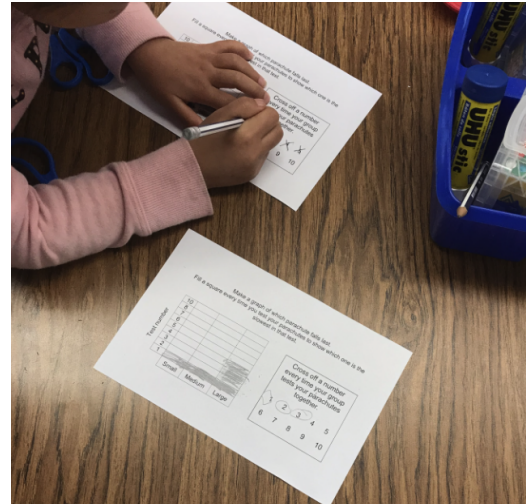


FIG. 5. Sample first-grade data collection worksheets

should be consistent with their motor skill development and be mindful of the time constraints of the activity.

Adapting for lower grades: When developing the parachutes curriculum for first graders, we considered ways to adapt the activity so that students could succeed. First, we simplified the parachute construction process and prepped most of the materials for them so that we could spend more time testing the parachutes. In addition to providing the pre-cut canopy squares, we pre-cut one-inch pieces of tape and equal pieces of string.

Adapting for higher grades: For sixth graders, we did less material preparation and gave students the responsibility of measuring and cutting string. We also had students determine the surface area of the canopy by measuring the sides of the square. If we had more time with the students, we could have also involved the sixth graders in planning the investigation and allowed them to choose the variable they focused on.

Adaptation 2: Data collection tools and organizers

Adapting for lower grades: A second change to the investigation was how students collected data to accommodate our first graders' beginning skills at reading, writing, and measurement and our sixth graders' greater facility with these skills. Like the third graders, the first graders identified which parachute fell slowest. They recorded their data by filling in a box for the small, medium or large parachute, skipping the step of writing a word and then constructing a graph from the data table (see Figure 5).

Adapting for higher grades: To increase the complexity for older levels, the sixth graders timed each fall and recorded the results in a data table. Students also worked together to make a class line graph to represent the relationship between canopy size and the time it took to fall.

TABLE II. Differences across selected grade levels.

Practice	1 st	3 rd	6 th
Practice 3: Planning Carrying Out Investigations	Assembled pre-cut materials (canopies, strings, washers). Dropped parachutes from 1 meter and observed the one that fell last (slowest).	Measured strings and constructed parachutes. Dropped parachutes from a height of 1 meter and observed the one that fell last (the slowest parachute).	Planned how to construct parachutes to test effect of surface area. Measured materials and constructed parachutes. Timed parachute falls and determined an average fall time.
Practice 4: Analyzing and Interpreting Data	Created bar graphs of data by filling in blocks for each trial.	Recorded data in a data table and then translated data table into a bar graph.	Each group measured time for parachute fall of a specific surface area. Class combined data to graph and draw a "best fit" trend line.
Practice 8: Obtaining, Evaluating, and Comm. Info.	Drew pictures, talked to table groups about ideas, created bar graphs.	Wrote short explanations, created bar graphs, drew models of ideas.	Wrote longer explanations, plotted data on a graph, drew models.

2. Practice 4- Analyzing and Interpreting Data

How students analyze and interpret data should be consistent with their learning of mathematics. While all grade levels can record numerical measurements and analyze the measurements using math and visual representations, appropriate data collection and analysis actually looks different at each grade level.

Adapting for lower grades: The youngest students who are learning to read and write may not be able to do so fluently which may make filling out data tables difficult. At the first-grade level, students are learning how to interpret data through comparisons across multiple groups. In this activity, students compared three different sized parachutes and determined which one fell the slowest by identifying the parachute that had the most number of colored-in data points as recorded in their bar graphs.

Adapting for higher grades: At the sixth-grade level, students are learning how to quantitatively analyze relationships between two variable. We used this as an opportunity to think about surface area as it relates to the measured time each parachute took to fall. We pushed the students to conceptually understand the relationship present between these two quantitative measures in order to come to an understanding of balanced forces that must be acting upon the parachutes. This was done through the use of data tables to inform the creation of labeled diagrams.

3. Practice 8- Obtaining, Evaluating, and Communicating Information

How students are asked to record and communicate information within a physics activity should be consistent with their ability to read and write.

Adapting for lower grades: To accommodate first graders' developing skills in writing and reading, the worksheet used was a guide to help students understand what was going on through diagrams and pictures. Students communicated ideas through sharing with a partner or the class. Unlike the third-grade students, first grade students were not expected to write their ideas in sentences.

Adapting for higher grades: The older students expressed predictions and findings through graphs, writing and diagrams. Students drew graphical representations of their predicted relationship between surface area of a parachute and the time it took to fall as well as explained their thinking to a partner. After collecting data, students explained the phenomenon by drawing a diagram. Students wrote explanations on the diagram as well as drew arrows to represent the forces acting on the parachute.

V. CONCLUSIONS

While the engineering design process as defined by NGSS broadly applies to all K-6 grade levels, the conceptual understanding of physics content expected at different grade levels differs. Similarly, children's math, literacy, and fine motor skills develop as they progress through elementary school. We identified three NGSS practices that were critical to thinking about how children at different ages engage with the outreach activity. Other practices, such as developing and using models, were also an important component of the activities, but not as useful in informing how we adapted the activity.

ACKNOWLEDGMENTS

This material is based upon work supported by the National Science Foundation (grant EEC-1824858; EEC-1824859)

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- [1] A. V. Maltese and R. H. Tai, Pipeline persistence: Examining the association of educational experiences with earned degrees in stem among us students, *Science education* **95**, 877 (2011).
- [2] R. Dorph, P. Shields, J. Tiffany-Morales, A. Hartry, and T. McCaffrey, High hopes—few opportunities: The status of elementary science education in california. strengthening science education in california., Center for the future of teaching and learning at WestEd (2011).
- [3] NGSSLeadStates, Next generation science standards: For states, by states, Appendix D: All standards, all students: Making the Next Generation Science Standards accessible to all students (2013).
- [4] P. Bell, B. Lewenstein, A. W. Shouse, M. A. Feder, *et al.*, *Learning science in informal environments: People, places, and pursuits*, Vol. 32 (National Academies Press Washington, DC, 2009).
- [5] W. R. Penuel, B. J. Fishman, B. Haugan Cheng, and N. Sabelli, Organizing research and development at the intersection of learning, implementation, and design, *Educational researcher* **40**, 331 (2011).
- [6] B. Bevan, Research and practice: One way, two way, no way, or new way?, Curator: The Museum Journal **60**, 133 (2017).
- [7] M. Agar, *Language shock: Understanding the culture of conversation* (Perennial New York, 1994).
- [8] N. R. Council *et al.*, Next generation science standards: For states, by states, (2013).