

## **Instructional Strategies in K-12 Informal Engineering Education - Deep Case Study Approaches to Educational Research**

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## **Instructional Strategies in K12 informal engineering education - Deep case study approaches to educational research**

K-12 informal engineering education can support student confidence, interest, and awareness of the field of engineering [1,2,3,4]. Studies have suggested that K-12 informal learning can influence students' awareness of the fields of engineering [5] as potential career opportunities. Researchers have also found that engineering activities outside of school can engage youth in disciplines of which they are unfamiliar [6] because of a lack of engineering opportunity in K12 formal education. In this paper, we provide a rich case study of one lesson's implementation in a 5th-6th grade girls afterschool program. Our intention is to provide an in-depth description of a lesson, the corresponding assessment using a validated assessment tool for informal learning of science and engineering, and data that suggest the concepts that were (and in some cases, were not) taken up by girls following the activity. We argue that a deep study of implementation can complement survey and large-scale studies that are more typical in engineering education research, as it allows for nuance in understanding how to effectively influence youth regarding engineering. The research questions that drive this in-depth study of one K-12 outreach activity are:

1. What instructional moves do afterschool youth educators use to support successful engineering design with elementary youth? And
2. What evidence suggested students did (or did not) come to understand scientific concepts as they related to balloon-powered car design?

### **Context of the study**

This study is part of a five-year research project with a non-profit organization called Techbridge Girls, focused on the design, development, and deployment of engineering activities in all-girls afterschool settings. In a Techbridge afterschool program, a series of activities takes place over an extended time-period, at least 12 weeks, with the same group of girls. Activities take place in their school, and supported by the nonprofit staff as well as a teacher in the school. All sessions include an engineering design experience in which students develop a design idea, build a product of some kind, test the product as it relates to the stated criteria and constraints, and consider design revisions. Designs are in line with recommendations in engineering education for focusing on process, redesign, analysis and evaluation [7]. These design experiences occur individually and in teams. Over a decade of evaluation data show that girls who participate in the afterschool program gain interest, confidence and awareness of careers in engineering [4].

The lesson addressed in this paper was balloon powered cars, and it was implemented with 19 fifth and sixth grade girls at Elm Valley\* elementary school. The lesson was primarily facilitated by Techbridge staff member Author 3, with support from the school teacher. Authors 1,2, and 3 were present for the activity. Author 4 designed the curricular unit. Rather than develop a test-like task, the research team followed the advice of the National Academy regarding assessment [8], and focused on process-based interviews that assessed the students' understanding within the context of the project they had just completed. Girls were interviewed along with their projects, which allowed authors the ability to examine artifacts from the lesson as participants described the different design elements they crafted.

### Methods: Data Collection

This in-depth case study focuses deeply on the implementation of one lesson in a K12 afterschool program. Through focusing in-depth on one lesson, it is possible to gain insight into how instructor's choices influence lesson quality as well as student development of conceptual understanding.

The case study method is a useful approach for *describing* and *explaining* phenomena [8] using naturalistic data. This case was bounded as the implementation of the balloon car lesson at Elm Valley elementary as the unit of analysis.

The data that inform this paper include the following:

- a) Curriculum documents for gravity-powered cars from Techbridge
- b) Extensive fieldnotes from the two-hour session with youth, including documenting dialog among participants
- c) Dimensions of Success Rubric assessment of the quality of the STEM out of school activity across 12 factors, with comparison to a large-scale study of afterschool STEM program observations
- d) One-on-one interview data from 10 girls who participated in the Techbridge activity using an artifact elicitation interview technique, analyzed by authors 1 and 2 (*please see ASEE paper # 22631 for more information on the design of the interview protocol*)
- e) consultation with the instructor for clarification

### Data analysis:

The purpose of the focused analysis was to document how an informal educator supported students' engineering design, specifically how she managed youth's progress and meaning making in a car design activity. In addition, interviews with girls following the lesson indicate whether or not girls achieved a greater understanding of the scientific concepts following the experience. In this case study, efforts were made to establish trustworthiness [9]. Data were analyzed using the constant comparative method. As hypotheses were made, all data were examined for confirming and disconfirming evidence. For example, the hypothesis that instructor's use of physicality assisted youth in understanding stability for car design was investigated in youth interviews, in observational data, and in artifacts.

### Establishing trustworthiness in analysis:

All authors have prolonged engagement with Techbridge, though authors 1 and 2 are external to the organization while authors 3 and 4 are internal to the organization. Data are triangulated as recommended by Patton [10] using multiple methods to gather data from sources (observation of and interviews with girls participating) more than one analyst to check interpretations (authors 1 and 2 analyzed interviews with girls) and more than one point of view for gathering data (specifically, girls' perspectives, instructors' perspectives, and observers' perspectives are taken into account). We provide thick description [11] of a lesson and its implementation in an afterschool setting in an effort to answer our posed research questions. Using thick description enhances the ability of readers to decide whether the qualitative data is transferable to another context. Negative case analysis is used in this case study to establish qualitative credibility—while some students were supported in understanding multiple conceptual elements of the

balloon car activity, not all were able to communicate these concepts following the activity, as we describe in the third results section.

#### Results: Overview

This section has three main parts. In the first, we detail specific curricular details as well as instructional actions made by the primary facilitator that, we contend, support girls' gravity car development. Second, we provide evidence of lesson quality from the Dimensions of Success observational tool, particularly focused on STEM content knowledge, inquiry, and engagement with STEM. Third, we utilize participant interview data to suggest instances where students indicate shifts in their thinking about their gravity car, and instances when they did not.

#### Results Part 1: Instructional actions

The primary facilitator used a multitude of strategies, both by curricular design and improvisationally through interaction with youth to support participants' successful car design.

Lesson implementation element	Description
Guided group discussion	Instructor engages youth in a guided, full group discussion that restates the concepts from previous activities, and provides opportunities to connect concepts to real world phenomenon. [12]
Constraints and Criteria	Instructor explicitly describes the criteria of the activity, as well as the constraints for the activity. [13]
Peer assistance	Instructor guides peer modeling, and supports peer to peer assistance as a successful learning strategy. [14]
Targeted questioning	Instructor uses questioning to support participant understanding and participant meaning-making. [15]
Physicality	Instructor uses gesture and physical motion to scaffold student understanding of engineering design elements. [16]

Table 1: Instructional strategies to support engineering design in afterschool learning

#### A. Guided group discussion of energy

*Teresa begins the hands-on activity with a review. "We are going to review energy- remind us what type of energy our cars used last week." A few girls call out "kinetic." Teresa nods, "And what is kinetic energy? Andrea." She calls, pointing to a girl at a table in the middle of the room.*

*"Kinetic energy is when it is in motion." Andrea says.*

*"What is the other type?" Teresa asks.*

*"When it stores the energy," says Izbel.*

*"yeah...I'll give you a hint- 'I believe in you because you have a lot of \_\_\_\_' " Teresa prompts.*

*"Power?" says Maria.*

*"Potential?" says Valentina.*

*"You have both of those things, but potential." Teresa says, smiling. "Why does the car have stored energy at the top of a hill? What is pulling it down?"*

*Two girls call out "gravity."*

*Teresa responds, "right. I want you to think about other ways potential energy can be stored." Girls turn to their neighbor and are tasked with coming up with other ways that energy could be stored. Some examples shared in the larger group are "when you are holding a balloon and let the air out," "a shake flashlight uses magnets," and "spring action doors." Teresa reminds them of another option. "You guys love this material- rubber bands."*

In the discussion, Teresa brings in the concepts of potential and kinetic energy, guides participants' thinking about different forms of potential energy, and makes connections to past activities girls completed the week before with designing cars. While she leads girls' responses through deliberate questioning, girls' ideas about potential energy are elicited, and girls are given time to share their responses with a peer before sharing with the larger group. This guided discussion is meant to prepare participants for the engineering design activity, creating a "cognitive structure" to support use of prior knowledge in the upcoming challenge [12].

#### B. Constraints and criteria define the goals of the activity

*As Teresa introduces the follow-up lesson to the gravity cars they discussed the previous week, she puts a slide on the screen with two columns, one with "criteria" and one with "constraints." Teresa states: "Remember constraints are the limits. We have new materials this week, binder clips and balloons." The introduction of new materials to the kinetic car activity provides additional opportunities for powering the cars the girls will develop so they can meet the stated criteria: roll down the ramp successfully and "travel the farthest" on the carpeted floor. Rather than provide instruction on how the balloons and binder clips should be used, the availability of new materials suggests an opportunity to enhance potential energy use for cars without dictating the methods of use. One participant had mentioned that balloons hold potential energy "when you are holding the balloon [closed]", which is a concept other girls could build upon in their designs.*

The Next Generation Science Standards for K12 note the importance of students' understanding of criteria and constraints in an engineering design project. By leaving the design open-ended within the criteria and constraints, girls have opportunities to decide for themselves how the balloon might provide additional power for their cars. The guided discussion of potential energy might support student thinking about balloon as a potential energy provider.

#### C. "Getting inspired" by other participants

*Two girls are sitting at their station with multiple materials- straws, cardboard, a balloon, and a clip. They pick up different objects, and appear to put them down without manipulating them in any way. Teresa approaches the pair. "We have been learning about wheels and axels- when one turns and the other stays still. You see them on cars. Your group needs to figure out how to put the axel on your vehicle. Walk around and get some inspiration."*

Teresa presented the pair of participants with an opportunity to learn from their peers by observing other groups and finding out how they were constructing their cars. Teresa describes the task as “getting inspiration” for their design, which indicates it is a positive design strategy, rather than a remedial move. Peer learning is an important element of informal STEM, and can be very effective in supporting development of both the learner and the peer coach in a conversation [13]. The instructor frames the peer learning when she lets the girls know what they are looking for—a way to connect the wheels and axels to the cardboard to allow wheels to spin. By sending the girls on a specific fact-finding mission, she propels their work forward without taking away opportunities to make design decisions.

#### D. Targeted questioning

*Teresa spends time circulating as the participants start to build their cars. She approaches groups with specific questions about their next steps, reminders to “draw those ideas in your notebook,” and reminders about how much time remains before they test the cars. She approaches a group that appears to be off-task, giggling to one another and with their hands and eyes off of the materials on the table they share. She approaches the table, and gestures to the balloon they chose. “So, it looks like we are working on a balloon-powered car. What are you thinking about the balloon position?” Teresa asks. The girls gesture to a position on the top of their car. Teresa continues to circulate, and observes another group with a balloon car. As they practice test the balloon car on a ramp, the car tips over. “What did you notice?” she asks. “What do you think could be happening with the position of the balloon?” the girls consider this question, and speak to one another. Teresa waits a moment, then moves to another table as the girls adjust the placement of the balloon.*

Teresa’s questions appear to serve multiple purposes, and research suggests instructors’ questioning strategies can be consequential in participant learning [14]. As she circulates and asks questions, she is drawing participants back to the design project, from which some have strayed. Accountability in afterschool spaces is less directive than in the formal classroom; using gentler classroom management techniques are often more appropriate than admonishing off-task behavior. Questioning the groups creates an opportunity for girls to communicate their design choices because girls must describe what they are doing to a third party. Finally, questioning can cue participants to important design decisions of which they may not be aware. Teresa focused in multiple interactions with youth on the position of the balloon on the car, indicating through the question that the position of the balloon might influence the motion of the car.

#### E. Physicality

*A pair of participants test their balloon car on the ramp, and mark their progress on the carpet. “Why does it do that?” one exclaims, exasperated. Teresa joins the group, and asks, “So it keeps turning, what can you do to stop it from turning?” she asks the pair. The girls mutter “I don’t know.” Teresa stands before them, puts her arms and legs out wide, and sways left to right “Is this more stable,” then she places her feet close together, swaying left to right again, “than this?” she asks. The girls confer, and Teresa calls to the room “time’s up, get your cars and please bring them to the front.”*

Teresa attempted to direct the pair to consider reasons why their car continued to flip over in testing. When she asked them directly they were unable to come up with a response regarding why their balloon flipped. Rather than suggest a cause, Teresa acts out the movement of the car using her body, first showing the girls how a more stable vehicle might be built (with wheels spread apart on the piece of cardboard) and second mimicking the girls current wheel positioning, closer together. This physical demonstration was meant to assist participants in understanding an important concept in their car design: stability. Educational research has shown the importance of gesture and physicality as important teaching strategies, particularly when youth do not yet know the terminology of a discipline—gesture and physicality can bridge the gap as students develop more expert understanding [15].

## Results Part 2: Dimensions of Success Tool validates lesson quality

The informal STEM learning community is invested in evaluating curriculum to measure the quality of the lessons implemented in afterschool programming. The PEAR institute at Harvard, directed by informal education scholar Gil Noam led the development of the Dimensions of Success Tool. A description of the tool from the website states [17]:

*“Dimensions of Success (DoS) is an overarching framework that defines key aspects of a quality STEM learning experience. DoS forms the backbone of a suite of tools and guides designed to help out-of-school-time (OST) programs (e.g., afterschool programs, summer camps, etc.) improve the quality of their STEM offerings. It was developed and studied with funding from the National Science Foundation (NSF) by The PEAR Institute, along with partners Educational Testing Services (ETS) and Project Liftoff. The DoS suite of tools allows researchers, practitioners, funders, and other stakeholders to track the quality of STEM learning opportunities and to pinpoint strengths and weaknesses.”*

Techbridge uses the DoS as a formative learning tool. DoS evaluation is conducted at least annually with each staff member. All leadership and coaching staff have been trained in the tool. In the context of the scale-up project at Techbridge, DoS has been a regular part of both research team and evaluation team data collection since 2014. Table 2 below is adapted from [18] and defines 6 STEM-specific elements that relate to the case study as defined by the NSF-funded instrument development. Overall, clear, compelling, and consistent evidence is required to rate a “4” on the Dimensions of Success rubric, while a “3” involves clear evidence of the element, which may or not be seen consistently across all participants and/or across the entirety of a program activity. The table shows the DoS description of the element, published mean scores from a study of 57 after school STEM program activities, and scores from the focal activity at Elm Valley. The Elm Valley activity that is the subject of this paper scored higher on nearly every measure of the Dimensions of Success elements related to the six dimensions that fall under “activity engagement” and “STEM knowledge and practices” headings.

DoS element	DoS criteria	Mean scores in study of OST STEM (n=57 observations, range 1-4)	Score in Teresa’s lesson (range 1-4)

Participation	Extent to which youth have access to materials and appear to participate in the activity	3.01	3
Purposeful Activities	Cohesiveness of each portion of the lesson and evidence that suggests each element of the lesson relates to the STEM learning goal(s)	2.77	4
Engagement with STEM	Opportunity for youth to construct understanding and actively participate in the cognitive work of the activity	2.52	3
STEM content learning	Youth can build and express their STEM understanding, which is connected throughout the activity and is presented in accurate ways.	2.28	3
Inquiry	Extent to which youth get to direct their learning through use of scientific practices (including engineering design) in authentic ways	2.28	4
Reflection	Extent of youth opportunity to reflect on their experiences, build new knowledge and discuss how what they learn in the current activity relates to prior knowledge	2.03	3

Table 2: Dimensions of Success Tool Comparative Data

The tool is not available publicly and requires an extensive training for its use, including a two-day workshop and calibration assignments that test the raters' understanding of the elements to be scored. Evidence from the DoS assessment of the gravity cars lesson with Author 3 at Elm Valley indicates the informal learning experience was of high quality, according to the measurement tool used. All ratings were either 3 or 4 on a 4-point scale, averaging 3.42 across the 12 dimensions. This average score places the lesson in the top tier of DoS assessments for this organization, as conducted by research and evaluation. The table also shows how the lesson compares to a national sample of afterschool STEM activities [18]. In all but one case, the lesson implementation rating for the target case exceeded the average in the national study.

Overall, evidence from the observation indicates youth had opportunities to “do the cognitive work” of the project, rather than to follow instructions or rely on information given by others. This element of design is important in distinguishing high-quality hands-on lessons, and is in line with engineering education design curriculum for this age group, such as Engineering is Elementary [19]. The entirety of the lesson was focused on engaging in STEM ideas, from the engineering design process itself, which was the focus of 100% of the time devoted to the lesson,



to science concepts such as potential and kinetic energy, which were essential for building the cars enhanced with wind power. A weakness of the lesson based on DoS scoring was the ability for all youth to communicate their knowledge about the designs they created—while many students could participate in the large group discussions, and all students tested their cars at one point, the verbalization of their scientific and engineering experience was not evident across all participants during the lesson.

#### Results part 3: interview evidence of participant understanding

Brief interviews were held with 10 girls who participated in their school the day following the afterschool program. Girls met with authors 1 and 2 during a lunch break. Girls had access to their cars, which was particularly useful for communicating details of their design ideas when they were unaware of scientific terms that related to their projects. The interviews were analyzed for conceptual themes, and patterns emerged regarding understanding across participants.

#### Interview data regarding axels

All participants interviewed were knowledgeable about axels and how they allowed wheels to turn. Many of them transferred their knowledge of axels from the previous lesson. Quotes from interviews appear below:

“My car wouldn’t move last week. Then I got inspired by my friends to put the wheel stick in the straw-then it could be moving inside the straw when the straw was taped to the car.”

“My car was moving better this week, but the wheels were kind of sticking when they spun- I think I want to adjust the axel so it can spin better.”

It appears that girls learned from previous experience that the axel was an important design feature for car building, a lesson they carried over into the balloon-powered car lesson.

#### Balloon as a form of power

Many students could articulate the element of wind power as a potential energy source utilized to propel car motion in some way. While the responses rarely focused on the terms “potential energy” or “force,” they did convey some understanding of balloon as a source of energy.

One participant stated the balloon “helped my car go a little farther” because “the air, when you let the air out it moved it.” Another respondent described how the air was held as potential energy for release. The girl described that she learned this element of the balloon car design from her peers when she was asked to get inspiration from other participants.

“I learned from other girls to use the binder clip to keep the air in. So I took their idea but I asked them first.”

Another interviewee stated the way she propelled her car: “you fill the balloon with air and you hope that the car would move from the air,” she stated.

#### Stability

As girls tested their cars, they were met with success and failure. Some balloon cars tipped as they travelled down the ramp, while others turned, making it difficult to rate their forward progress against the straight-traveling cars. In the final test phase, one car was the clear winner, traveling much faster and farther along the ramp and the carpet than other competitors. In interviews, girls shared conflicting theories about why the car was successful. One of the girls who designed the winning car was sure that the design idea to tape the wheels on the top of the car made the difference. Her partner did not consider this an important design feature, however.

Other girls who witnessed the winning car described wanting to place their car wheels on the top of the cardboard as well, because they thought it would make a difference in their success—specifically, they mentioned that the wheels on the top would “keep the car from flipping over.” Three interviewees noticed the element of the car that they thought set the winning car apart from their own- the wheels on the top. They described a redesign that would focus on putting the wheels above the cardboard rather than below. They failed to mention other elements of the car—the space between the axels, the relatively firm connection of the axels to the cardboard, and the length and width of the car’s base.

In reviewing the lesson, Teresa described remaining misconceptions this way:

*“Many of the cars had their axels placed too close together (so the cars were kind of short from front to back). Not distributing that stability made the cars flip over when the balloon was placed on top. This was particularly a problem when the balloon was placed near the front of the car, because it caused more torque around the front axel.”*

While some misconceptions about design strategies remained, some girls were receptive to the notion that balance and stability in their design might be the difference maker. Teresa cued this idea during the lesson, specifically when she moved her body with her feet held far apart, and then again with her feet held close together. The quotes below show how some girls were beginning to wrestle with the concept of stability in their car development.

*“If I had a chance to redesign I would make the wheels more stable. They were already taped to the cardboard so we left them there and just moved the balloon (during redesign time in the lesson). With even more time with the wheels we could even measure (the distance between the wheels).”*

*“When we tested the car, we noticed that the car turned so they asked us how could we make that better- we went to our desk to try to fix it and we thought it was unbalanced.”*

*“I think it is how the weight of the balloon in the front was too heavy and tipped it.”*

## Discussion

Engineering design activities allow K12 youth to practice thinking like engineers in an informal setting, and allow youth to drive their own efforts. Understanding whether and how youth pick up the scientific concepts that are salient to the design is important for measuring lesson quality and student advancement. In-depth lesson study can bring out practical instructional strategies that strong educators use to move youth forward in their engineering design processes while still maintaining ownership of their activities. Interviews with youth following their work can elucidate which concepts were understood by many, and which ideas are still elusive to those participating in the afterschool program.

RQ1: The instructor utilized 5 specified instructional strategies to support youth in an informal learning opportunity in engineering design. guided group discussion, explicitly defining constraints and criteria, supporting peer assistance, the use of targeted questioning, and use of her physicality to assist student learning. Interviews following the lesson indicate that these moves were successful in supporting some youth in deeper conceptual understanding. The lesson as implemented was demonstrated to be of high equality, exceeding the average score on all but one of 8 Dimensions of Success tool elements highlighted in this work. The instructional

strategies detailed follow best practices in formal education, and yet they transferred well to the informal education setting.

RQ2: Despite the high-quality lesson implementation, interview data was mixed regarding student uptake of concepts and use of the concepts in the building of their balloon powered cars. While most participants understood axels in this lesson, and many conveyed understanding of balloon power, stability was not well understood across participants. The lesson case study suggests the need for multiple opportunities in informal settings to build knowledge related to engineering design.

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