

Implementation of an Engineering Summer Camp for Early-Elementary Children (Work in Progress)

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Susan earned a B.S in Industrial Engineering from NC State and has worked in the

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Susan now works for The Engineering Place, the K-12 outreach arm for NC State University's College of Engineering, as a coordinator for Outreach. Her main responsibility is to manage the week long Day and Residential Summer Engineering Camps for rising 3rd through 12th graders in Raleigh and throughout the growing number of partner locations throughout the state of North Carolina. Over 1,700 children will be attending one of her engineering camps during the summer of 2015.

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In 2017, The Engineering Place at North Carolina State University began hosting a summer camp for rising kindergarten through second grade students (approximate ages 4-8). Of the myriad engineering camps offered each summer, either at this organization itself or elsewhere, most do not target early-elementary students. This echoes the general trend of focusing on the later grades in engineering education and missing an opportunity to introduce engineering to students who are full of creativity and curiosity, and who are open to all the developmental possibilities that engineering concepts can provide. This endeavor is a work-in-progress and our paper describes how the design of the camp was informed by both the theoretical foundation of early-elementary engineering education, and the practical methods adapted from work with older audiences, to introduce engineering related concepts like an engineering design process and engineering habits of mind to younger children. Elements of the camp include the use of literature to contextualize daily design challenges and provide bridges between activities, the use of scaffolding for activities to “level the playing field” for students with diverse backgrounds and skill-sets and to assist with shortcomings in fine motor skills, and the identification of strategies for developing student confidence and positive attitude toward failure. This paper also discusses the stratified structure of teams for camp management and content delivery, and the importance of K-12 teachers partnered with engineering undergraduate students in the implementation of the camp, as well as lessons learned by each of the constituencies. Preliminary assessment results include informal surveys and focus groups, coupled with observations of camp and video clip analyses. Preliminary results revealed that students learned how to treat failure as a positive tool. Several lessons were learned about how to facilitate hands-on activities with students whose fine motor skills and 2-D to 3-D visualization skills have not yet developed.

Introduction

The Engineering Place at North Carolina State University, a large, public university, has been conducting engineering summer camps for over fifteen years [1]. Several design elements of the summer camps include: the staff for the camps is assembled from a combination of engineering educators, K-12 educators, engineering undergraduate students, and high school students in a tiered mentoring arrangement that has had long term impact on all of the participants. The camp curriculum is linked to cutting edge research activities in the College, with specific attention to the tenets put forward in the NAE document, Changing the Conversation [2]. The attendance at the camps averages 30-40% female and 35-40% underrepresented ethnic minorities with no specific targeted recruiting.

Early research at The Engineering Place [3] indicated that children, and girls in particular, were making decisions that would lead them either toward or away from interest in STEM disciplines. For this reason, and to be consistent with a goal of recruiting a diverse

group of students to engineering, the suite of engineering camps offered began with upper elementary school students (ages 7-10). Since that time, further research has shown a tendency among girls to avoid activities identified as belonging to children who are “very, very smart” as young as age six. [4] If the program was going to guide students toward STEM disciplines without having to overcome pre-established notions of who should be interested in them, it became clear that younger students; specifically, rising kindergarten through rising second graders (ages 4-6) needed to be exposed to fun and exciting engineering activities.

Few other programs for early childhood exist around the United States. Tufts University offers a LEGO™-based camp for first and second graders. Other search results found for-profit summer camps that associate engineering with robotics or particular disciplinary foci, such as aerospace or civil. In addition, there are programs for early childhood learning as a part of outreach programs, [5], as an example.

Hammack, Ivey, Utley, High (2015) [6] examine an engineering summer camp for middle school students, which was only 3.5 hours a day. Their work showed attitudes toward engineering changed significantly after camp (for the positive), but not attitudes toward science, indicating that their camp achieved its goal of increasing students’ awareness of what engineering and engineers are.

The design of The Engineering Place summer camps is significantly different. For these youngest elementary school students, the focus is not on career education so much as it is toward problem solving, creativity, working with others--in point of fact--engineering habits of mind [7].

Multiple approaches to engineering curricula for younger students have emerged in the last ten years [7] [8] [9] [10] Some lean on robotics, some on LEGO, but two in particular place their engineering problems in the context of stories. EIE [8] and Novel Engineering [10] use story books (custom or trade) to provide context for the youngest of engineering investigators. This literacy-based approach [11] provided inspiration for the design of activities for the pre-K-second grade students at this engineering camp.

Early-elementary engineering is an area that has been historically neglected in education research. While reports and meta-analyses on pre-college engineering often run from “K” through 12th grade, a majority of the research corpus is focused at the middle and high-school level, with a few studies reaching down into the upper-elementary grades [12]. In Crismond and Adams’ *Informed Design Teaching and Learning Matrix* [13] for example, engineering practices are described for novice designers through not-quite-expert informed designers, but studies drawn on to provide evidence of behaviors for the so-called “beginning” designers focus on novices at the university level, and are generalized to lower grades. We do not believe that the engineering design behaviors of an early-elementary student will, or should, look like those of a

college freshman. If the *Matrix* cites little evidence from elementary students engaging in engineering design, that is in part due to the lack of available data. Some notable studies include Portsmore's [14] investigations of how kindergarten and first-grade students use drawing for planning, Wendell's [15] clinical interviews with third-grade students as they evaluate properties of building materials for creating design solutions, or Kendall's [11] observations on how kindergarten students attend to design constraints.

In practice, the lack of engineering opportunities for kindergarten through second-grade students is due to many factors, some of which include teacher familiarity or comfort with teaching design, engineering, and technology subjects [16] , and a focus on literacy and math standardized testing in the early grades, with STEM subjects like science not being assessed in [this state] until fifth grade. At the time of writing this paper, a search of the NSF-sponsored TeachEngineering.org website--a peer-reviewed repository of standards-aligned engineering activities, lessons, and curricula--produced only 28 entries recommended for grades K-2, out of 1660 total K-12 entries in the database [17].

Camp design

Adding the richness of a scenario and background via a storybook, campers connected the project work they were doing with a broader cause. During the first day, we read Mr. Bear Squash-You-All-Flat by Morrell Gipson to introduce and connect to an activity that involves designing a house that can withstand the weight of a giant stuffed bear without collapsing. The second day's book was I Am Not a Chair! by Ross Burach and introduced the day's activity of designing a chair that could be used by a hippopotamus. The chair had to be designed to fit the size and shape of a weighted hippopotamus puppet. The third day involved the very relevant Rosie Revere, Engineer by Andrea Beaty. The day's activities involved doing a team Rube Goldberg activity that included 9 campers. The fourth day involved reading Going Places by Paul A. Reynolds. The day's activities involved both designing a 'going machine' that can be launched in the air and travel on land and designing a Nano Bug maze that directs the bug to travel in multiple directions and distances. The final day of camp involved the book Billy Bloop is Stuck in Goo by Jennifer Hamburg. The book introduced the activity involving the campers making slime.



Figure 2: Camp participants review one of the story books for the week

The six engineering habits of mind [18] that we use at camp are Creativity, Optimism, Collaboration, Communication, Systems Thinking and Ethical Considerations. These habits directly support the approach that the campers exhibit for each of our engineering activities. At the end of each day, we identify campers from each team that best demonstrates each of the habits to provide them with positive reinforcement, as well as define through action what the model should look like. To assist with communication, dry erase whiteboards (2'x3') were used along with engineering notebooks to promote clearer communications and to bridge the gaps between writing abilities. By using this tool, campers were able to effectively display their thoughts and ideas regarding their engineering design activity. By end of week, the campers were able to grow from drawing their own separate pictures to collaborative and connected drawings. Each child had a different color marker that helped indicate their addition to the design and collaborative effort. At the end of each day, all campers and staff members met to test team projects and discuss challenge activities. Based on testing procedures, a rubric was used and scores were given based on how each team's design performed. Each day, campers engaged in a short conversation regarding failure, successes, and ways to improve designs in the future. To compliment afternoon challenges, explorative scaffolding was paired with daily challenge activities connected with literature.

With twenty-nine rising kindergarten to rising 2nd grade campers, three teams were created with a team leader (K-12 teacher), two counselors (engineering undergrad students), and nine to ten campers in three different break-out rooms. Assistant counselors (paid high school students) are also available to work on the management and distribution of materials needed for engineering activities, help with outdoor time, support the drop-off and pick-up process and manage the lunch distribution process. A lead assistant counselor managed the day to day actions of the

assistant counselors. The demographics of the camp participants included a total of 29 students (38% female and 62% male). The racial and ethnic makeup of the students was 10% American Indian/Alaska Native, 10% Asian, 45% Black/African American, 28% White, and 7% that did not report their race/ethnicity. Among the attendees, 24% were on free/reduced price lunch and income levels of parents/guardians varied. 7% students came from households that made below \$15K a year, 17% that made between \$15K-\$30K, 14% that made between \$35K- \$50K, 4% that made \$50K-\$75K, 48% that made over \$100K, and 10% did not report their household income.

The agenda (see Figure 1) for the camp provides scaffolded activities throughout the morning to allow students to build background knowledge and understanding of engineering concepts. In the afternoon, students are given adequate time to collaborate and utilize the engineering design process to complete an engineering challenge based on a book that identifies a real-world problem that needs to be solved.

Scaffolding activities are selected to support the larger activity that is planned for the afternoon. Scaffolding activities break down the components of the larger activity enough that a focus can be made to gain perspective and mastery before having to manage doing all of the elements together. Scaffolding activities are similar to a procedural activity in that direction is provided on what is to be accomplished. If you think of the directions and photos used to assemble a piece of Ikea furniture, or a pre-modeled LEGO structure, then you have the basic design of a procedural activity. A creative activity involves the goals and constraints without a clear direction of how to accomplish the task. The only thing that is clearly known is how the outcome will be evaluated. Scaffolding falls between procedural and creative because of the importance of the inquiry process and its relationship to exploration. During the exploration process, the campers get the opportunity to guide their learning and understanding towards the larger scope.

Time	Monday	Tuesday	Wednesday	Thursday	Friday
8:45-9:00	Drop Off	Drop Off	Drop Off	Drop Off	Drop Off
9:00-9:15	Camp Introduction	Activity Introduction	Activity Introduction	Activity Introduction	Activity Introduction
9:15-9:30	(Meeting Place)				
9:30-9:45	Scaffolding Activities: Stacking Cups, Toothpick/Marshmallow Towers, Mega Blocks	Activity: Build a Better Bug	Activity: Human Rube Goldberg	Activity: Puff Mobiles, Spatial Reasoning, Nano-bug Exploratory	Activity: Squishy Circuits
9:45-10:00					
10:00-10:15					
10:15-10:30					
10:30-10:45					
10:45-11:00	Outdoor Time	Outdoor Time	Outdoor Time	Outdoor Time	Outdoor Time
11:00-11:15					
11:15-11:30	Lunch	Lunch	Lunch	Lunch	Lunch
11:30-11:45					
11:45-12:00					
12:00-12:15	Activity Introduction	Activity Introduction	Activity Introduction	Activity Introduction	Activity Introduction
12:15-12:30	Story Time: Mr. Bear	Story Time: I am NOT a Chair	Story Time: Rosie Revere, Engineer	Story Time: Going Places	Story Time: Billy Bloo is Stuck in Goo
12:30-12:45	Squash-You-All-Flat				
12:45-1:00	Activity: Design a House that a Bear Can Sit on without Collapsing	Activity: Design a Chair	Activity: Team Rube Goldberg	Activity: Design a "Going Machine", Nanobug Mazes	Activity: Slime
1:00-1:15					
1:15-1:30					
1:30-1:45					
1:45-2:00					Set up for Open House
2:00-2:15					
2:15-2:30					Open House with Straw Rockets, Nanobugs, and Stacking Cups
2:30-2:45					
2:45-3:00					
3:00-3:15	Daily Closing (Meeting Place)	Daily Closing (Meeting Place)	Daily Closing (Meeting Place)	Daily Closing (Meeting Place)	
3:15-3:30					
3:30-3:45	Pick Up	Pick Up	Pick Up	Pick Up	Pick Up
3:50-4:30	Team Meeting	Team Meeting	Team Meeting	Team Meeting	Team Meeting

Figure 2: 2017 K2 Camp Agenda

Results from year one camp

There were many opportunities for learning what worked well, what not so well, and what we could do to adapt and improve after year one. It was clear that campers and teachers were invested in the program and worked well together in planning and executing how to engineer and foster engineering habits of mind for this age group. To capture additional perspectives and results of the camp, post-camp surveys were distributed to teachers and intermittent semi-structured camper interviews conducted during camp activities. The brief interviews were video recorded and questions focused on extracting campers' thoughts about failure--what failure means to them, what they do when their project fails--and other insights regarding what they had learned about failure in camp. The following reports main ideas from teacher surveys and camper interviews, and is followed by a synthesis of what worked, what didn't work, and what changes are needed.

After the camp, teacher reactions and ideas were collected. Below is a sample:

Teacher observation of student reactions

- The students loved testing what they made. They were always engaged during the tests.
- What if we had group (as a room) tests more frequently before the camp tests?
- Campers had difficulties with 2d to 3d translation.
- Campers benefitted from the 1:3 ratio teacher to student team.
- Students learned about failure and learned it was okay to fail.
- Students were always engaged.

Teacher thoughts on classroom management

- Develop and facilitate the idea as a room, then decide which teams will construct the different parts, then go to work.
- Teachers were at times overloaded with individual campers that required a lot of attention. The effort and attention to get these campers involved took away from potential guidance and teaching of the other campers. However, when that camper got involved and wanted to participate in an acceptable way, you could see growth in interest and effort to test ideas, work with others, and problem solve.
- Campers worked well with other campers for the most part. Campers helped each other work through their ideas.
- The “Rube Goldberg” was a hit once campers caught the vision and tried to work as a team. However, it took a few times practicing as a whole group before they saw that vision and became focused on accomplishing the task.

Teacher takeaways

- I learned a lot about scaffolding activities for that specific age group and what needs to be done for them to explore engineering.
- Campers began to try to use everyday objects to create things at home, from discussions I had with parents.
- Parents were surprised with what students had designed and were more open minded about the idea that younger students can engineer too!

Campers’ perspective on failure

The idea of learning from failure was a specific focus at the camp and contributes to their knowledge of what engineers do. With all the design tasks the campers were building, there were many projects that failed their designed purpose. Below is a table of some of the questions asked to the campers and their responses during a design task.

Table 1: Camper responses to failure

Camper	What do you think about failure?	What do you do if/when your project fails?	Inquiry questions	What have you learned about failure
Camper 1	<i>“Keep trying and don’t give up”</i>	<i>Keep trying</i>	Why do you keep trying? <i>That’s what engineers do</i>	If you fail don’t give up

Camper 2	<i>"It's good"</i>	<i>"Keep trying"</i>	Why is it good? <i>it teaches you a lesson</i> What lesson? <i>That you never give up</i>	----
Camper 3	<i>Its kinda good because you can't win all the time</i>	<i>It's when you do something that's not right.</i>	What do you do when your project is not right? <i>Always try again</i>	<i>It's when you do something that's not right</i>
Camper 4	<i>That it's good</i>		Why is it good? <i>If you fail, you can try again next time</i> What is good about trying again? <i>Next time you might learn</i>	<i>You can get better at it</i>
Camper 5	<i>I feel not good, but i can always try again</i>	<i>Think about how to make it better</i>	What do you do if you want to try again later? <i>You could ask</i>	<i>I feel sad</i> Why do you feel sad? <i>because I fail and I don't have time to try again</i>
Camper 6	<i>When you don't succeed and you try again</i>	<i>You try to reset it again</i>	How do you do that [reset it again]? <i>By taking it apart and thinking again.</i> What do you think about? <i>What you do to make it better</i>	----
Camper 7	<i>I don't know</i>		Why don't you know? <i>I don't know</i>	
Camper 8	<i>I don't know what failure is.</i>		Why not? <i>I don't know how to learn what failure is</i>	
Camper 9	<i>I don't know</i>	<i>Think about what I did wrong. If I could I would fix it</i>	Why do you have to think about why you have to fix it [your project]? <i>Because next time I don't want it to fail</i>	
Camper 10	<i>bad</i>	<i>Improve them</i>	Why is it bad? <i>Cause you fail.</i> What do you do to fix failure. <i>Success</i> How do you improve them? <i>Add more stuff</i>	

			What do you mean? <i>Add more stuff</i>	
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What went well?

There were many successes throughout the camp. The camp also provided a 1:3 ratio between staff members and campers when working in teams. This allowed us to guide campers and effectively manage teams. The range of fine motor skills varies widely in K-2 students based on age, experience, and gender. In order to accommodate the range, a variety of tools and techniques were provided. For example, tools such as scissors were provided in different sizes, stickier duct tape was used instead of masking tape to hold structures together, and hot glue was not used in the creation and construction phases. Each of these changes from approaches used in camps for older students worked well for these younger campers.

To ensure that campers' various learning needs and preferences were met, exploratory activities were scaffolded before introducing the main challenges. When campers were introduced to Nano Bugs, each camper was first given their own bug to explore how it functioned and reacted to its environment. Campers practiced with mega blocks and other materials in the afternoon to complete mini challenges such as, make the bug go in a straight line, create a tunnel or door, make the bug travel down a three inch decline, and make the bug go 360 degrees.

Another scaffolded activity was cup stacking. This introductory activity made it easier to understand how to build a sturdy house in the afternoon. The same type of knowledge building strategy was used as students created Rube Goldberg Machines from smaller to larger systems and by creating straw rockets and then creating 'Going Machines' in the afternoon.

One of the best ways the camp staff collaborated was through the end of day staff meetings. Every day the camp coordinator, lead assistant counselor, team leads and counselors would meet to review the day's proceedings and prepare for the next day. Camper concerns were addressed and discussed, activities were reviewed and amendments were planned. Plans were then implemented in the schedule for the following day and throughout the week. Supply needs and changes was an essential aspect of each day's discussion.

Considering the environment of being on a college campus and the need to engage campers, the week concluded with an open house to display and demonstrate what campers had learned. This was in lieu of a closing presentation, as was done in previous older-aged camps. The open and flexible format of having parents come and go when they pleased, walking through the different rooms observing and discussing completed and tested artifacts, and participating with their campers in various activities was an extremely effective way to bring closure to the program, while giving exposure to the week's activity.



Figure 3: Camp participants work on the human-sized Rube Goldberg challenge

But most of all, campers and teacher team leads learned that failure was necessary and needed for personal growth. Many of them left camp saying that they wanted to be challenged. (identified through video).

What didn't work well?

There were various aspects of the camp that did not work well. Compared to the upper elementary campers that attended our other camps, the rising kindergarten through second graders' fine motor skills were at a different level that was not accounted for when planning all of the activities. While students were expected to be able to complete tasks like build a three dimensional figure with marshmallows and toothpicks, they were unable to do so. Considering the size of their hands, the background knowledge they may have, and how they needed to manipulate materials during the activity, camp staff saw that they could benefit from larger materials to complete this challenge.



Figure 4: Fine motor skills sometimes represented a challenge

In regards to two and three dimensional figures, many campers drew non-dimensional figures on whiteboards and could not translate their ideas to construct three dimensional objects, especially during the “Build a Better Bug” activity. The camp staff realized that a scaffolded conversation about how to create a three dimensional figure and how that could be accomplished (because bugs are not flat until you step on them) was needed.

In other activities, “Squishy Circuits” and “Make Your Own Slime”, scaffolding from a procedural activity to a creative activity was a barrier. A circuit challenge was introduced in the morning, and, while campers could not understand how to utilize conductive and insulator dough to complete a circuit, they quickly picked up on how to make slime using an assembly line. It’s possible that switching the timing of activities and scaffolding would allow campers to progress to activities that require more independence and stronger understanding.

The end of day closing session was modeled after the 3rd through 5th grade camps [1] and didn’t fit well in this camp. The format involved discussing the results of each of the activities done during the day, acknowledging the winning camper teams by bringing them up to the front of the camp, and having the winning teams explain their design and the process they experienced in

achieving their success. The end of day also included each team teacher lead recognizing certain campers from their team that best exhibited the habits of mind that day, as well as a dining award for the camper(s) who exhibited commendable lunchroom behavior. Due to the limited gathering space and the general restlessness of the campers, it was difficult for all three teams to sit together for this closing and became apparent that a different model was needed.

What needs to be changed?

To improve the logistics and implementation of the camp, various changes will be made for future sessions. Habits of mind books will be used along with engineering challenge books to encourage students to work collaboratively, be optimistic, creative, and communicate effectively. In addition, during transitional times and after activities, more structure to camp games and songs will be included to allow this age group to take brain breaks. Additionally, a more accessible, structured breakout room will be created.

Camp staff noticed that the available furniture was restrictive. The mobility and size of the tables and chairs may have constricted space for creative design, planning, and construction while giving campers more room to move about from group to group. Clearly, a trade-off regarding space existed. Planning for future camps will include considering alternative or flexible set-ups. Additional changes will be towards developing a more engaged and meaningful end of day closing program appropriate for the age group and gender ratios. Although this was the youngest group of campers, only 38% were female. Future recruiting efforts will continue to work towards a 50:50 ratio of girls to boys in order to contribute to girls' exposure to engineering, so they are better informed and engaged, planting a seed of possibility for a future career in engineering.

Conclusions and next steps

The Engineering Place will continue to implement a K-2 engineering camp as a part of the summer repertoire. Despite the combined research and practice experience of the university and K-12 teachers that planned and implemented the camp, there were still many lessons learned. Children who have not yet been a part of a formal educational setting need more explanation and guidance in team-based activities. Future work will include a more formal assessment of the lessons learned by the students in the camp, including the impact on their next year's participation in school (if any) of their introduction to teamwork, productive response to failure, and the other engineering habits of mind, a large part of what engineering can contribute to K-12 education.

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