The Future of Engineering Education
2024 Annual Conference & Exposition
Oregon Convention Center
Portland, OR . June 23 - 26, 2024
Paper ID #43349

A Collaborative Approach to Implementing Design Thinking and Rapid Prototyping in a High School Engineering Camp

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Abstract

Design thinking and rapid prototyping can be used to engage high school students and get them excited about pursuing a career in engineering. Engineering educators and a librarian at the University of Nevada, Reno collaborated to explore this concept and develop a makerspace activity that emphasized creative problem-solving and hands-on learning experiences designed to engage the students in an iterative design process with real-world applications.

Each summer, the College of Engineering hosts various weeklong camps for middle and high school students with a particular theme or engineering focus. During the summer of 2023, the DeLaMare Library Makerspace supported this program by hosting several design thinking and rapid prototyping sessions to accompany the already robust camp curriculum.

Over the course of three 1-hour sessions, students worked in small groups to explore human-centered design principles and fabricate a prototype. The first session was an introduction to the design thinking process and the tools available in the makerspace. Each team explored the theme of accessibility in the outdoors, and went through an abridged version of the first three steps of the design thinking process. By the end of this session, they had defined a problem and determined one solution from a structured brainstorming session. The second session was dedicated to fabrication of their solution using makerspace equipment, with help from makerspace staff members. During the third session, students received feedback from another group and had the opportunity to revise their designs before they presented the final product at the summer camp open house at the end of the week.

This paper will discuss the collaboration between the College of Engineering and the makerspace librarian, as well as detailed information on the goals of the project, the design thinking curriculum, session facilitation, and lessons learned. This will provide a useful guide for other institutions that are interested in incorporating design thinking or rapid prototyping into their K-12 engineering outreach efforts.

Keywords

Curriculum, design thinking, diversity, makerspace, maker literacies

Introduction

Engineering occupations are projected to grow significantly, with expected increases of 3-26% from 2022-2032 across the U.S. [1]. The range includes 3% for general engineering up to 26% for software developers [1]. To address this demand, engineering professional organizations, such as the National Society of Professional Engineers [2] recommends providing outreach opportunities to promote engineering careers to K-12 audiences. University engineering programs can fill this gap to promote their educational programs to youths in their regions. They can begin to integrate skill development with their outreach sessions to promote desired engineering skills, or habits of mind, such as problem solving, collaboration, creativity, communication, ethical considerations, innovative thinking, etc. [3]. Recognizing the importance of this preparation, the College of Engineering at the University of Nevada, Reno coordinated summer camp programming for middle and high school students to introduce them to engineering disciplines and get them excited about pursuing an education in this field. The College of Engineering summer camp program primarily focused on exposing students to various engineering disciplines by providing tours through campus engineering laboratories, presentations from faculty members and engaging in camp-led engineering design challenges.

The DeLaMare Library Makerspace at the University of Nevada, Reno provides access to making equipment and tools for students, faculty, staff and community members. While the space is primarily used by university students, the makerspace staff works closely with K-12 University-led programs during the summer months to provide activities for camp participants. These activities utilize hands on learning as the students engage with makerspace competencies and machinery. Connections to campus K-12 programs strengthen campus partnerships and support the universities' objective of introducing prospective students to university resources.

The DeLaMare Library Makerspace comprises a footprint of 3,000 square feet, spanning two rooms and encompasses the entirety of the first floor of the library. This library primarily serves the STEM majors, but we welcome all students to use our resources at University of Nevada, Reno, which comprises nearly 21,000 undergraduate and graduate students. The makerspace contains equipment like laser engravers, vinyl cutters, 3D printers, 3D scanners, CNC milling, sewing machines and more. There are dedicated work tables throughout the space that are moveable to create a classroom and allows the space to be flexible and adapt to the various makerspace instruction sessions. The flexibility of the teaching space has been crucial for instruction, as there is no dedicated classroom in the library, and the main makerspace room limits up to 35 people.

The DeLaMare Library Makerspace has been a long-time partner with the College of Engineering summer camp program, often used as a space to tour through and view the various equipment available to our campus community. This collaboration began years ago, when the College of Engineering summer camp staff reached out to the makerspace staff to request a tour of the space, to show summer camp participants the various resources available on campus. Through the years, the makerspace staff have offered the incorporation of engaging activities, to enhance to summer camp participant experience. Some years, the makerspace provided one-shot sessions, with activities like button and sticker making or engraving images onto their camp provided aluminum water bottles.

In the summer of 2023, a new opportunity presented itself to make engineering education even more relevant and engaging to these students. The College of Engineering camp coordinator reached out to the fabrication librarian to discuss a change in the summer camp program, with the desire to implement a new engineering design challenge. In previous years, these challenges were designed by the camp coordinator to be done within the camp classroom, using basic crafting materials and no intervention from the makerspace staff. With the changes to the new engineering design challenge format, this challenge would become a week-long project.

The coordinator requested to have the fabrication librarian develop the engineering prompt and curriculum, ensuring that the students had access to develop a prototype using makerspace equipment and tools. This change prompted the fabrication librarian to develop new curriculum and adapt concepts from the University of Texas, Arlington's (UTA) maker literacies and the Hasso Plattner Institute of Design at the Stanford University, or d.school, design thinking model. While these frameworks are primarily used for academic courses at the University of Nevada, Reno, they were adapted for this high school engineering summer camp. Over the course of the week, summer camp students participated in three makerspace design thinking and prototyping sessions. The student groups designed and prototyped a solution for an outdoor recreation accessibility focused engineering challenge.

This paper will focus on the practical applications of the Stanford University d.school design thinking model and UTA maker literacies that were embedded into the curriculum for an engineering summer camp for high school students. The application of the curriculum will be explained through a detailed examination of the sessions facilitated by the fabrication librarian. The results will discuss limitations of the sessions and lessons learned, as well as planned alterations to the curriculum to enhance sessions for the 2024 summer camp season.

Design Thinking and Maker Literacies Background

Design Thinking in Education

Design thinking is a user-centered design process that utilizes empathetic techniques to engage with users to understand their needs and experiences to design a product that addresses a challenge [4]. It is used in educational institutions as a constructivist approach to teach problem solving skills through a creative and iterative process [5]. There are various frameworks that examine design thinking notions, often aligning similar methodologies to facilitate the acquisition of skills in communication and problem solving. In essence, design thinking prompts a group of designers to identify needs and acknowledge experiences of a target audience, generate a problem statement, brainstorm ideas to solve that problem, fabricate a representation of an idea and gain feedback from the target audience [6].

Sam Seidel, from the Stanford d.school [7] believes that these frameworks are appealing to educators, as they enable their students to gain empathy for others and increase confidence in their own creative ability. Stefanie Panke [4] conducted a systematic literature review of design thinking in various educational settings. Among the K-12 research, Panke [4] found that teachers perceived design thinking as a positive experience and saw the value in these transdisciplinary learning experiences, bridging the gap between STEAM and other disciplines. Teachers also believed that the implementation of these concepts into the curriculum enhances student skill acquisition in computational thinking, collaboration, communication and creativity [4]. Based on this study, design thinking can provide the skills that are desired by engineering disciplines, such as creativity, communication and problem solving [3]. By implementing design thinking sessions into K-12 curriculum, students can begin to hone these skills and practice becoming empathetic engineers in the classroom.

Design Thinking Framework

Among the various frameworks for design thinking, the Stanford University d.school is a leading institution for their model and highly developed resources. They offer a bachelor's and master's degree program, creating future leaders in design thinking approaches, promoting a transdisciplinary curriculum [8]. In addition to on campus offerings, they provide professional education opportunities and open access resources. Other practitioners can use this method to facilitate design thinking instruction into K-12 and university applications. Of these resources, the educator activity guides are a valuable toolkit for practitioners to seamlessly integrate a lesson into the classroom. These guides include topics on designing for organizing data, social change, belonging and more [9].

The d.school design thinking method encompasses five stages that connects the students with a challenging scenario and facilitates the use of human-centered techniques to creatively design a solution. These stages include empathize, define, ideate, prototype and test. In the empathize stage, which aims to understand the humans, or users, behind the challenge. This phase encourages students to consider the physical and emotional needs of those affected by the challenge and captures their experiences. There are several approaches to completing the empathize stage, which can include taking notes and gathering data by observing the users' actions or interviewing them [10].

While students participate in the define stage, they distill the data collected and identify themes, key insights and needs of the user. The goal is to understand human experience from the information collected and develop a problem statement that narrowly focuses on a consideration or challenge that was addressed by the user [10].

The ideate stage focuses on idea generation for solutions that could be designed to address the problem statement. Several divergent techniques can be used to guide students to generate multiple ideas, including brainstorming, bodystorming, sketching, etc. [10].

The prototyping phase generates an artifact or representation based on an idea that was developed in the previous stage. This artifact can be a physical 3D object, 2D sketch, storyboard, roleplay activity or digital product. The prototype will be used as a communication tool to garner feedback from the user and to test the feasibility of the design [11]. Prototyping is an iterative phase, where students may create multiple versions of a design to address various components or be redesigned based on feedback. Early stages of prototyping are typically low-fidelity and fabricated using cheaper materials and rapid prototyping techniques, like using 3D printers or hand crafted with paper [12]. After a series of iterations to a design, a high-fidelity product will be developed, that exhibits intended functions and mimics a final, polished product [13].

The testing phase gathers feedback from the users to test the feasibility of the prototype, understand if the user needs were met and learn more about the user experience. The users will be asked to interact with the prototype, and the students take notes on valuable insights gathered based on the design. Based on this feedback, future iterations can be developed to further narrow the design scope [10].

UTA Maker Competencies

The appeal to the design thinking process comes with its' versatility, providing an activity that can be done in any classroom or learning environment. The design thinking process incorporates making concepts, where students engage in hands-on learning experiences, often fabricating a physical product using basic crafting materials or utilizing making technologies. Makerspaces are a natural fit for design thinking concepts to be facilitated, as they provide space for creative pursuits with fabrication equipment, including 3D printers, laser engravers, sewing machines and more [14].

Makerspace environments foster creativity and innovation and provide alternate ways to learn and engage with course content, especially when linked to the engineering disciplines [14]. Makerspaces are a valuable tool for an academic institution, especially among engineering disciplines who utilize making equipment for prototyping projects for coursework. Morocz et. al., [15] found that engineering students who are encouraged to use academic makerspace for coursework are more motivated and less anxious when performing engineering tasks. This positive correlation supports the idea that makerspaces can benefit students, and in the past decade we have seen more spaces dedicated to making for engineering students and other disciplines.

With the development of more makerspaces within academic institutions, there was a need to address the gap in competencies by tying course curriculum to makerspaces. Nearly a decade ago there had not been much work tying student learning to subject based learning outcomes or measuring the impact in makerspace curriculum [16]. To address this gap, the University of Texas, Arlington assembled an ad-hoc taskforce from various universities to develop a national standard of maker-based competencies to enhance student learning outcomes to impact undergraduate students [17]. Among the taskforce was the University of Nevada, Reno. In 2017 and 2019, the group received two National Leadership grants from the Institute of Museum and Library Services (IMLS).

To form their framework, the grant team used the competencies-based education model, which includes the assessment of learning outcomes and learning that is personalized, measurable, and transferable [16]. Ten maker competencies were developed, addressing various transferable skills that could be learned through the making process. Student learning outcomes were designated for each competency, and a rubric was built out to for educators to map learning outcomes to broad themes that may align with learning goals, including inquiry, foundational practice, manage practice and transferred knowledge [18].

The grant team based their competencies to support The National Association of Colleges and Employers (NACE) Job Outlook 2016, which stated that employers value the ability to work in teams, communication skills, creativity, strategic planning, etc. [16]. Based on these values, the competencies address various transferable skills that can be used among various disciplines, and aimed to be transcended out of the classroom and into the workplace. To aid in the assessment of student learning, this framework provides educators a way to integrate maker literacies into academic curriculum and gauge "learning in both the affective and cognitive domain" [16]. Competencies are as followed [18]:

1. Identify and articulate a need to create.
2. Analyze and explore ideas, questions, problems, and potential solutions.
3. Create effectively and safely.
4. Assess the availability and appropriateness of tools and materials.
5. Prototype using iterative design principles.
6. Develop a project management plan.
7. Engage in effective teamwork.
8. Employ effective knowledge management practices.
9. Apply knowledge gained into other situations.
10. Understand ethical and intellectual property issues surrounding making.

Instructional Context

The fabrication librarian, Rebecca, used these frameworks to develop new curriculum for a design thinking activity that would engage students to work as a group to design a product using makerspace tools and equipment to help an identified audience. An engineering design challenge prompt was developed, with a focus on accessibility in the outdoors. Accessibility has been a focus in the DeLaMare Library Makerspace in the past year. Alterations to the makerspace environment were made to meet various ADA regulations and universal design principles, and new tools were purchased to accommodate various disabilities. This project aimed to create an inclusive and more usable space for makerspace users. This project provided inspiration for the summer camp design challenge, with the goal of encouraging the students to consider how to design for diverse populations.

A secondary inspiration for the prompt was from the Innevation Center, another makerspace at the University of Nevada, Reno, which developed an outdoor themed design challenge for a local competition they hosted earlier in the year [19]. This prompt focused on accessibility in the outdoors. After consulting with their makerspace specialist, the fabrication librarian developed a prompt to reflect their design challenge, with a specification in water recreational activities.

The prompt [appendix] explains the types of challenges individuals with disabilities may face, specifically defining mobility impairments. This definition provides context, so that they understand what accessibility is, and how modifications can benefit people. The task was to create a product designed to improve water sports accessibility for all.

The fabrication librarian spent an estimated eight hours designing the curriculum, including researching prompt topics, adapting currently used design thinking activities for the middle school audience, developing the worksheet and creating the presentation. With the librarian having experience with developing curriculum for design thinking, this estimation may be low compared to a library staff member who would need to dedicate more time to understanding design thinking concepts. This can be possible for library staff who are tasked to develop instruction session in their makerspaces, but they should be mindful of the amount of time it may take them to grasp a good understanding of design thinking in order to facilitate the concepts.

Student Learning Outcomes

The makerspace curriculum was developed using concepts from the Standford d.school design thinking model [10], following the five stages of the design thinking process. The first three student learning outcomes derive from concepts of design thinking. Students were expected to be able to complete the empathize, define and ideation phase of the model through a guided activity. Student learning outcomes four, five and six are based on the maker literacies [20], where students use the skills learned to develop a prototype, iterate based on feedback and learn safety skills while using makerspace tools and equipment. The learning outcomes for the makerspace sessions are as followed:

1. Students will be able to identify challenges using observation techniques.
2. Students will be able to identify a problem based on the challenges they observed.
3. Students will be able to use one ideation technique to develop various solutions to the identified problem.
4. Students will be able to identify the different types of prototypes.
5. Students will be able to revise and modify prototype design over multiple iterations.
6. Students will be able to create effectively and safely.

Workshop Methods

Setting and Participants

Over the summer of 2023, the College of Engineering ran several one-week long summer day camps, where students engaged in engineering activities and short lectures from engineering faculty members. Each camp has a different theme and engineering focus. The fabrication librarian developed a design thinking activity for the Engineering Exploration: Introduction to Engineering Camp and the Mechanical Engineering: Motion, Force and Energy! Camp. These camps are five days long, Monday-Friday from 8:30 am – 4:00 pm each day.

While both camps had different educational experiences throughout the week, the makerspace prompt and sessions were the same for both. There were no repeat students between the two camps, which allowed the makerspace to teach the same lesson to both groups. Each camp spent three sessions in the makerspace, spanning over three days. Each session occurred during the last 60-75 minutes of the day and was separate from the rest of the camp curriculum. Students did not work on their engineering challenge outside of the makerspace, as they were busy attending lectures from faculty members on various engineering topics, touring engineering labs and taking a fieldtrip to an engineering facility in town.

Both camps were designed for students 15-17 years of age. The mechanical engineering camp had 13 students, while the engineering exploration camp had eight students. Groups were formed with two to four students each, with a total of three groups for the mechanical camp and three for the engineering exploration camp. Groups names were created by the fabrication librarian to distinguish between each of them. In the mechanical camp, we had group A, group B and group C. In the exploration camp, we had group D, group E and group F.

Makerspace sessions were led by Rebecca, with assistance from the makerspace specialist and one student worker. Three employees were needed to roam around the makerspace for each session, providing assistance as needed to the groups as they fabricated using various machines and tools. There were two engineering camp counselors at each session, helping to manage student behavior and occasionally aided in generating ideas for fabrication and using hand tools.

There was no formal assessment conducted during the makerspace sessions and the camp participant artifacts were not graded. To demonstrate the makerspace session and product outcomes, there will be a detailed account of the session workflows, accompanied by examples of participant artifacts and observations made by the librarian.

Workshop Materials

The makerspace provided various materials to use in the making process. These following items were purchased using library funds, and are freely available year-round for all users of the makerspace. Camp participants primarily used extra “scrap” materials that were left over pieces from previous makerspace users projects that were left behind for free use. The College of Engineering did offer to purchase material for this activity, but the makerspace staff declined due to the extensive scrap material offerings. In the future, the makerspace staff will take inventory of items, and have the College of Engineering supplement the used materials. The items included:

- Construction paper
- Scrap wood with varying thicknesses and sizes
- Two-inch-thick foam boards
- Cardboard
- Various scrap fabrics
- Vinyl sticker material
- Rubber bands
- Popsicle sticks
- Various sized wooden dowels
- Modelling clay
- Acrylic paints
- Various screws, nails and other hardware.
- Various tapes
- Various glues

Students were given access to the two laser engravers, two vinyl cutters and a variety of hand tools available in our tool cabinet. The makerspace has other equipment available, including 3D printing, CNC milling, sewing and more. Due to the limited time of each making session, makerspace staff designated these four machines and hand tools because of their ease of use and quickness to produce a product.

Session 1:

During session one, students were introduced to the design thinking process. This session was split into two components, the first where they learned about the five stages of design thinking and the second where they were immersed in the process.

Rebecca presented on the five stages of design thinking via a PowerPoint presentation, primarily focusing on the prototyping phase. The presentation featured a short video clip from the MIT IDM Altitude Design Process video [21], providing a real-life example of the ideation and prototyping phase.

The presentation moved onto a more detailed description of the prototyping stage, explaining the types of purposes of prototypes as communication methods, integration into more complex systems and as milestone achievements. There was also an explanation of various types of prototypes, including analytical, focused and comprehensive. They then moved onto discussing the differences between low-fidelity and high-fidelity prototyping. Finally, the methods of prototyping were mentioned, which linked back to our makerspace and how the machines and resources can be used. This section took 35 minutes to complete.

The second component of this lesson gave the students hands-on experience in the design thinking process. The students were put into groups. The librarian provided a prompt, explaining that each group would identify a challenge, develop a problem statement, ideate solutions to that problem and design blueprints to one solution. Over the course of the next two sessions, students would prototype their final design using makerspace equipment. To guide the students, Rebecca continued with the PowerPoint presentation, with slides guiding the students through the activity.

Students were encouraged to chat about the types of accommodations or modifications that they have seen in their lives, with Rebecca providing examples of how the makerspace has made modifications for our community.

Now that the groups had been given their prompt, they moved into the define stage. They were given a worksheet to fill out as they identified challenges from the provided images. These images were of several people with various mobility impairments recreating on or near water. Images include people moving through a sandy beach in a wheelchair, getting into a kayak, paddleboarding with prosthetics and more. The students were asked to work as a group to make observations and highlight potential challenges that these people may face because of their visible mobility impairment. They were asked to write a few challenges per image. They were then asked to identify one challenge that they would develop a solution for.

During the ideation stage, students were each given two sheets of paper and asked to silently brainstorm two solutions to their challenge. They were encouraged to draw out their ideas, using bullet points or annotations to describe various components. They then passed their two ideas to the group member to their right. With two ideas in front of them, they were asked to review these ideas and provide suggestions, ask clarifying questions and/or draw extension to the ideas. They then passed the ideas around one more time and reviewed these new-to-them ideas. This repeated until everyone in the group had seen all ideas that were generated. This activity promoted a diversity of ideas, with each student given the opportunity to generate solutions from their unique viewpoint. The group discussion fostered the communication of all ideas that were generated, with staff encouraging groups to combine components of the ideas to find a product that could be best for the intended audience. Justifications were made, and each group agreed on one final solution. Through this process, each student had a voice, and the solution was the ownership of the group.

Session 2

The second session started in the makerspace, with groups sitting together. The librarian showed a few examples of prototypes on a PowerPoint slide and did a brief tour of the makerspace to explain the machines that are available in the makerspace. For this session, students were limited to using laser engravers, vinyl cutters and hand tools. This provided easy access to facilitate this session with the makerspace staff members and ensure that students had enough time to complete a low-fidelity prototype in the allotted time. Groups were given a deadline to complete their prototype by the end of this session.

Groups were then given material options and allowed to begin prototyping. Groups worked with makerspace staff members to discuss their ideas, offer advice for materials, and assess the appropriate machines to achieve the desired effect. At the end of the session, each group left their projects in a box in the makerspace, to be stored overnight.

Session 3

The third session was designed to garner feedback from other groups, and re-design based on this feedback. The intent was to use a structured activity via PowerPoint, where two groups would partner and discuss their prototypes. Due to the lack of time management in session two, this activity was scraped so that the groups had more time to build their prototypes in session three. By the end of session three, groups had a complete prototype that they took with them back to their camp classroom.

These prototypes were featured at the summer camp reception on the last day of camp. Parents of campers were invited. Rebecca attended this reception and talked to each group about their challenge and solution, having them explain the components of their design. They were encouraged to think about the design choices they made, and how it related back to their challenge.

Student Design Projects

Based on their discussion, groups identified a challenge and developed a problem statement, and produced two objects to demonstrate how they would solve the problem. The output was a 2D drawing of their design and a 3D physical prototype.

Identified Challenges

The groups chose varying challenges to focus on, and distilled to the following topics:

- Wheelchairs getting stuck in the sand: Groups A and B

- Getting in and out of recreational equipment: Groups C and D
- Transition between land and recreational equipment for lower extremity amputations: Group E
- Wheelchairs being left behind in the sand while recreating in the water: Group F

Drawings

During the ideate stage, groups brainstormed and determined one solution to the challenge they identified. They developed simple, hand-drawn blueprints for the solution, annotating the drawing to articulate the varying components and functions. These drawings demonstrated various adaptive devices.

Groups A and B focused on wheelchairs getting stuck in the sand and had similar approaches to their design. They both made alterations to an existing wheelchair tire to increase the width of the wheels and increased the depth and shape of the tread to provide more traction in the sand.

Groups C and D focused on getting in and out of recreational equipment and had two separate approaches but focused on people entering and exiting recreational equipment from a dock. One developed a kayak that had a mechanical seat that moves vertically and laterally using a hand-held remote. Two axes were needed so that the seat would be lifted vertically and then to the left or right over the dock. This provided ease of access to transition to the seat, rather than having to step down into it or step up off it.

The second design was a device that would be attached to the end of a dock, with a mechanical arm that has a 90-degree bend. This device rotates around a center pivot point, to move the arm from the dock over the recreational equipment that is in the water. A seat was attached to the end of the device and would raise or lower using a chain. The person could take a seat on the dock and then be moved over a kayak, and then be lowered down.

Group E designed for the transition between land and the recreational equipment for those with lower extremity amputations had a simple adaptation to an existing prosthetic device. They knew that prosthetic legs were commonly used devices, and wanted to enhance the foot with rubber treaded materials to provide traction. They designed this foot with webbing between the toes so that the person could swim more powerfully, basing the design on flippers.

Group F designed for the wheelchair being left behind in the sand while recreating in the water developed a wheelchair that could go in the water. This motorized wheelchair had a propellor placed in the back and was remote controlled. When turned “on,” the propellor would start and the flotation device located above the wheels would inflate. This would allow the wheelchair to stay afloat and the person’s torso to remain above water.

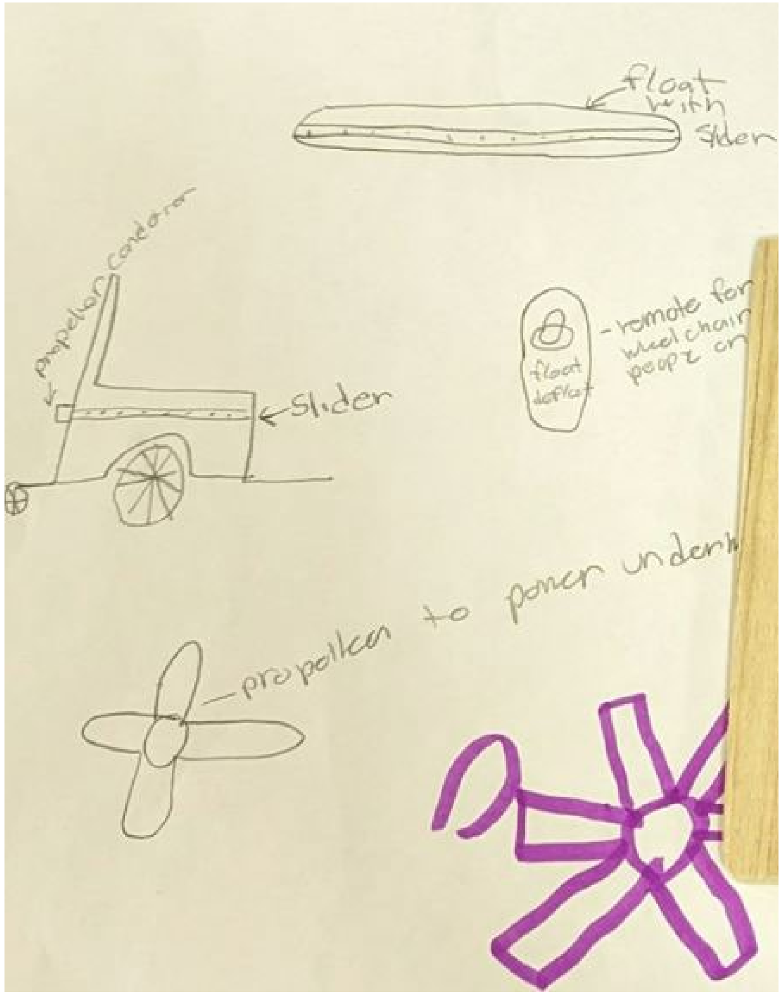

Figure 1: Group F student sketch design of a motorized wheelchair highlighting two components: the flotation device and the propellor.

Prototypes

During the prototype stage, groups used various materials and makerspace equipment or tools to develop a low-fidelity model of their design. Due to the material and time constraints, these rapid prototypes were developed on a small scale, under 12 inches in length and height. Groups were prompted to highlight the most important components of the design, rather than a fully fleshed out design to ensure they met their deadline.

All groups were creative in their making, as they all used multiple machines and tools to achieve the desired effect. Most groups used a mixture of laser engravers, vinyl cutters and various hand tools.

The laser engravers were the most popular, with groups A, B, C and F using it for one or more components of their design. Group A and B designed custom wheels in Illustrator as a flat image with a treading design on the outer portion of the wheel and holes in the center. They laser cut the wheels on 1/16 inch or 1/8-inch-thick wood. Group A also used 1/16-inch wood to laser cut components of the seat, later to be assembled with tape and metal hinges. Group C designed their crane-like apparatus in the Fusion360 CAD software program and exported it as a 2D file and used the laser engraver to cut out of 1/8-inch-thick wood. Group F used the drafting tools in the laser engraver software program to design arrows and an on/off button to be engraved on wood to create a remote.

Figure 2: Prototype built by Group C that used a laser engraver to cut a crane device out of wood.

Group B used the vinyl cutter to create a sticker of the name of their product to be placed on the back of their wheelchair.

Hand tools were another popular item. Group B used the hand tools, such as a saw and Dremel tool to shape their wheelchair out of two-inch foam and to cut dowels to be used as wheel axels. They cut out fabric to place on the seat and assembled all components with hot glue. Group C used a saw to cut dowels to be placed within their crane design to move their wooden seat up and down using string. Group D used a saw and Dremel tool to shape their kayak out of two-inch foam, and a saw to cut pieces for their seat, remote and paddle. They used hot glue to assemble the chair components to a metal spring for the seat. Group F used a saw to cut the propellor shape out of two-inch foam, and cut the wooden dowel to be placed on the back of the propellor. They used fabric and hot glue to create a portion of the flotation device.

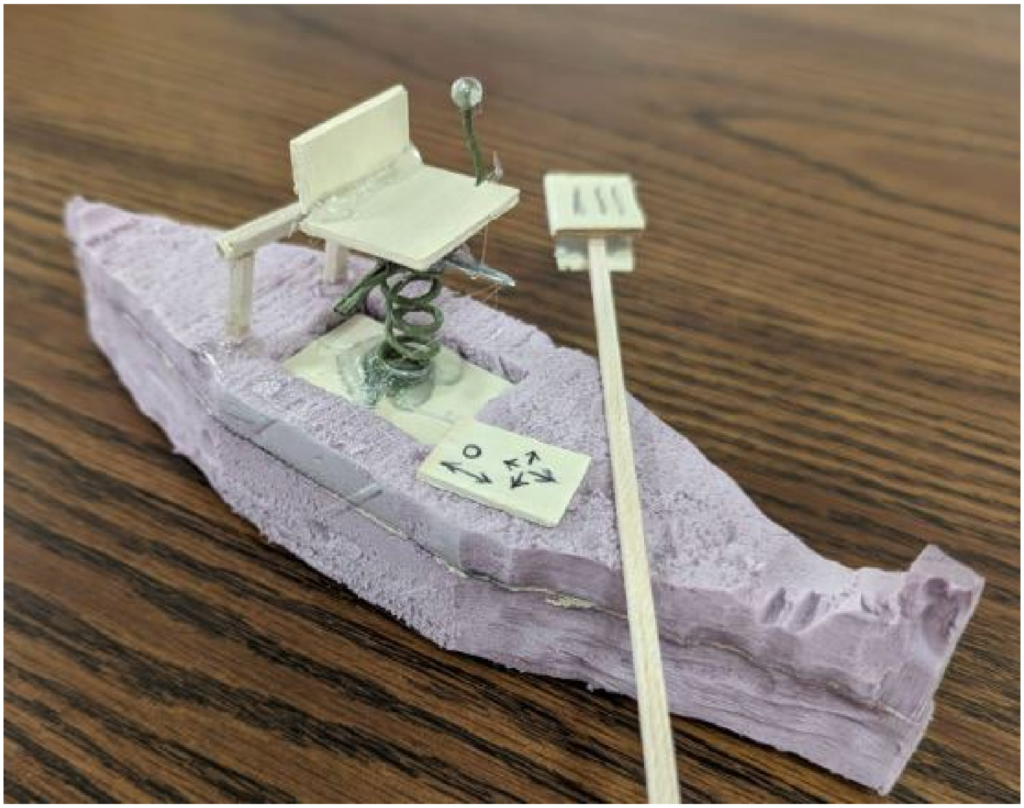

Figure 3: Prototype built by Group D that used a Dremel hand tool to create a kayak with a spring-loaded chair.

Group E did not use any tools, and hand molded the prosthetic design with clay, inserting a popsicle stick in the center for stability, a rubber band as the strap to adhere to the person's waist and sandpaper as the treaded foot.

Discussion

With this curriculum adapted for high school students, the librarian was impressed with the depth of creativity in the designs and how groups were able to fabricate these prototypes with little to no experience using these software programs and equipment and tools. Groups were able to manage their teamwork with each student participating in all stages of the process. As Rebecca observed the prototyping stage, it was rare to see a student not working. They were often consulting one another for design choices and divvying up tasks to spread the workload.

Define and Ideate

Overall, students were engaged with the design thinking session, and expressed interest in designing a product to help someone. However, there was some difficulty keeping the groups on track with each stage of the process. For example, in the observation activity there was one group that began to brainstorm ideas for one challenge they identified, rather than continuing to identify multiple challenges. This challenge also appeared when groups were asked to develop a problem statement. They began to brainstorm solutions, instead of discussing the problem they wanted to solve.

The structure of the session allowed the librarian to roam the room and talk with each group about their observations, problem statements and brainstorming ideas. This allowed Rebecca to guide the conversation, asking the groups to reflect on their thought process. As these challenges arose, it offered an opportunity for her to discuss the importance of each individual activity and how each built upon one another to form a well-thought-out design.

Prototyping and Feedback

Students seemed to be pleased with the use of makerspace equipment in this activity. Throughout the sessions, Rebecca heard comments from students expressing their interest to continue to use the laser engraver and vinyl cutter for future personal projects. Some expressed that this was their first time using these pieces of equipment and wanted to learn more regarding various applications of the equipment in engineering. Some asked how to access other equipment not available to them during these sessions, specifically the CNC mill and the 3D printers.

Time Management

The prototyping stage was an overall success, with each group completing at least one prototype. Although they had completed a prototype, there was a limitation to the curriculum which did not provide enough time for groups to feasibly fabricate with makerspace equipment. Prototypes were expected to be complete at the end of session two, and the librarian took note that all groups had incomplete prototypes at that point.

Rebecca adapted the curriculum on the fly to add in more time to prototype during session three. This led to the removal of the feedback activity, to ensure students had enough time to fabricate. With this session being 60 minutes, there would not have been enough time to complete the prototypes, receive feedback and redesign and build. This was not ideal, as the students would not complete the student learning objects to receive feedback to revise and modify the prototype design over multiple iterations.

Possible adaptations for future sessions could be to work with the camp coordinator to build more time in the makerspace. The 60–75-minute sessions did not seem long enough to complete the full design thinking process, where 90-minute sessions could provide enough time to complete an initial prototype and reiterate based on feedback. If timing is constricted for the summer camp schedule, then the librarian will need to prepare students for the time limitations. Makerspace staff can intervene regularly with the time management component so ensure groups are efficient with their fabrication time.

Staff Limitation

There was a total of three staff members facilitate each prototyping session. Staff members were not assigned per group, but they were tasked with floating around the room to help individuals as needed. Most groups split up tasks among their members, leading our staff to be pulled in multiple directions with the various impending needs of each individual student. This led to a backlog of requests from students, slowing the progress of the group projects.

An example of a limitation is with the laser engravers, which required a staff member to facilitate the digital drawing of the file in Illustrator and then demonstrate the operation of the machine. This requires extra time, as they are teaching two skills during one consultation. Luckily, one student in Group C knew how to use AutoCAD and was able to mock the design up and export a 2D file to import into the laser engraver program. Other groups did not have these skills and were reliant on the staff member to guide them through the process of designing and importing the file into the laser engraver program.

For some students, this was their first-time using hand tools, such as a Dremel tool and a saw. To ensure that they had a safe experience and achieve the safety learning outcome, the staff spent time with each individual who used the tools to ensure that they were properly trained to use each tool and understand the importance of personal protective equipment and safety with others in the space. This meant that the staff had to quickly get through the training so they could help other individuals with various needs.

Ideally, this limitation would be solved with the increase in staff members who would facilitate the use of equipment and tools. This is difficult to achieve, as makerspaces are often limited in the number of staff members in the space, or with the budget to have more than one or two staff on the schedule at a time. An alternative would be to train the summer camp staff members to help facilitate the use of makerspace equipment and tools. Providing a makerspace training session for summer camp staff before camps begin could prove beneficial, so they know what to expect from the session and have an assigned role while in the makerspace. This would allow one library staff member to lead the session and have one or two summer camp staff to support the making.

Machine Use

Most of the groups used makerspace equipment or tools to fabricate their prototype. While the use of equipment was not required of the students, it was highly encouraged. The intention of this newly developed curriculum for the engineering summer camp program was to expose the students to design thinking skills and makerspace equipment. In recent camp programs, they did similar activities but using basic crafting materials in their designated classroom. This new curriculum was intended to enhance the student experience by using makerspace equipment and tools to help build more robust prototypes and understand how this equipment can be used in real-life applications.

Four groups used two or more machines to create their prototype and is displayed with the following graph.

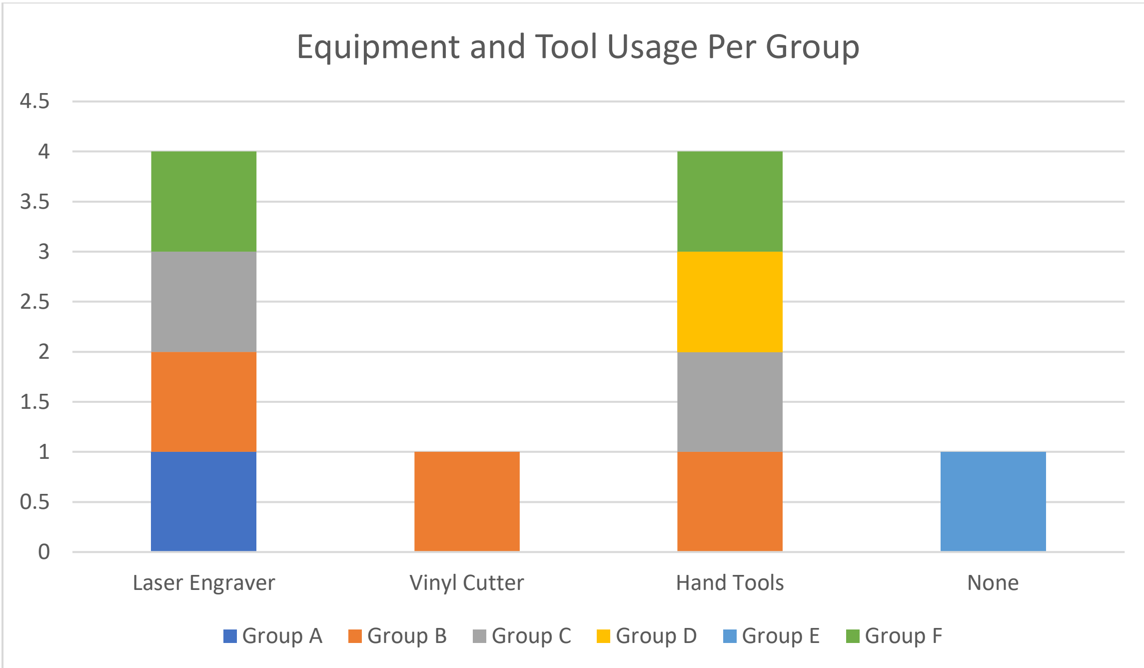

Figure 4: The distribution of makerspace equipment and tools used by each group.

Group E did not use any makerspace equipment to build their prototype, but instead chose to mold the prototype with their hands using clay and other materials. While they achieved the design thinking learning outcomes, they did not utilize makerspace equipment. This was an overarching goal for the makerspace and the summer camp coordinator, with the intent to tie the use of makerspace equipment and tools to the practical applications of engineers in the development of rapid prototypes in the field. Prototypes are an important component to mechanical engineer's work, to ensure their products are feasible before becoming manufactured. An intervention by makerspace staff during fabrication sessions could have been done to encourage this group to use at least one machine or tool to achieve this goal.

Conclusion and Future Work

This curriculum explored the concepts of design thinking and rapid prototyping in summer camp sessions for high school students. This work discusses how the design thinking sessions were facilitated within a university library makerspace and the end products that were developed by camp participants. Camp participants developed prototypes to solve a problem based on the prompt of accessibility in the outdoors, using laser cutters, vinyl cutters and hand tools.

The results of the sessions suggest that students were engaged with the design thinking process and were interested in developing prototypes, but needed reminders to stay on track with the phase they were in and advance to a later stage. All students were engaged with the prototyping process, each tasked with constructing a component to later assemble as a group. The laser engravers and hand tools were used more often, and three groups used two or more tools to meet the needs of their design.

There were limitations to the time management and staffing for the sessions, finding that students did not have enough time to develop a prototype within the time allotted and adjustments were made on the fly to ensure every group had a finished product by the end of the third session. A contributing factor to this was the inefficiency of the staff members' time, where they were often requested by multiple participants at once leading groups to wait.

While most groups utilized makerspace equipment or tools, one group did not use any equipment to fabricate their prototype. This group was not exposed to the resources the makerspace had to offer. This was a crucial component to the makerspace sessions, to enhance the student experience in using equipment and tools to develop a prototype.

Adaptions will be made for the 2024 summer camps, to address the limitations that were exposed during the 2023 sessions. The first will be to assign a staff member to one-two groups during the first session. This staff member would consult with the groups to understand the project needs and help them assess the appropriate materials and machines and develop a plan for managing their time during the prototyping phase. The intent will be to increase productivity during the second session, so that the students can dedicate the third session to giving feedback and reiterating their design. Second, the prompt and student learning outcomes will be adjusted to include a requirement to use at least one piece of equipment or tool, with an explanation of the importance of makerspace equipment in the development of prototypes by practicing engineers in the field.

While the curriculum was designed specifically for the College of Engineering summer camps, the fabrication librarian does have the intention to incorporate design thinking concepts at the collegiate level within the College of Engineering coursework. With a number of courses within the College that could benefit from design thinking, it is important to map the curriculum to mindfully place the concepts throughout the courses so the students are immersed and have a solid understanding by the time they graduate.

Overall, both sessions were deemed a success by both the DeLaMare Library Makerspace staff and the College of Engineering summer camp staff. The benefits were to introduce high school students to campus resources in an engaging way and increasing the visibility of the library to the greater public community. Students walked away from this experience learning how to thoughtfully develop a product for an identified audience using the stages of design thinking to inform their prototype design.

Acknowledgment

The author would like to thank the College of Engineering Outreach Department at the University of Nevada, Reno for their coordination of the summer camp program and including the makerspace as a component to enrich student engagement. Their support was crucial in providing key documentation regarding the summer camp programs to develop the background of this paper.

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Appendix

Design Thinking Prompt

Individuals with disabilities may experience differences in their:

- Mobility
- Cognition
- Vision

- Hearing
- Selfcare and more!

They face many potential challenges relative to equity and access to outdoor recreation activities. Whether with gear, infrastructure, equipment, clothing, or more, this market generates numerous opportunities and significant potential for innovation and improvement. Mobility impairments range from lower body impairments, which may require use of canes, walkers, or wheelchairs, to upper body impairments that may include limited or no use of the upper extremities and hands. Mobility impairments can be permanent or temporary. According to the Centers for Disease Control and Prevention, accessibility is "when the needs of people with disabilities are specifically considered, and products, services, and facilities are built or modified so that they can be used by people of all abilities" [22].

Your task: Create a product designed to improve water sports accessibility for all!