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MAKERSPACE TO CAPSTONE: PLANS AND PROGRESS TOWARDS AN INTEGRATED K-12 DESIGN THINKING AND STEAM CURRICULUM

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Berkeley Preparatory School is dedicated to preparing students for an ever-changing future. From the MakerSpace in Lower Division, to the Elder Digital Lab and the Smith Fabrication Studio in Middle Division, to the Best Design Studio and Lasher Design Studio in the Upper Division, we are focused on providing opportunities for students to imagine, design and create. Our school's vision statement of "Berkeley puts people in the world who make a positive difference" is being weaved into all elements of learning. Technology, making, and design thinking are all valuable skills in creating a mindset to achieve this goal.

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Peter Vogel is the Middle Division Design Arts teacher at Berkeley Preparatory School. He has a Master's degree in Architecture and more than 30 years of experience as a designer, fabricator, and artist. He was a Senior Lecturer at Otis College of Art and Design. The desire to share his passion with younger students is what brought him to Berkeley Preparatory School.

Meghan Campagna is the Middle Division Technology Coordinator and OpenLab Teacher at Berkeley Preparatory School. She has a Master's degree in Curriculum and Instruction and 10 years of experience in education. She is interested in effectively integrating technology and the maker movement into the curriculum. She enjoys working collaboratively with faculty and giving students the opportunity to engage in maker projects.

INTRODUCTION

Berkeley Preparatory School was founded in 1960 and is a prekindergarten through 12th-grade independent day school located in Tampa, Florida. Berkeley is accredited by the Southern Association of Colleges and Schools, the Southern Association of Independent Schools, the Florida Council of Independent Schools and the Florida Kindergarten Council. Memberships include the National Association of Independent Schools, National Association of Episcopal Schools, Center for Spiritual and Ethical Education, Secondary School Admissions Test Board, Association of Independent School Professionals, National Association of College Admissions Counseling and the College Board. There are currently 1,300 students enrolled in the school: 400 are in the Lower Division (PK-5), 325 are in the Middle Division (6-8), and 575 attending the Upper Division (9-12). There are 155 students in the graduating Class of 2017. The student body is culturally diverse and we have a strong scholarship program. The pupil/teacher ratio is nine to one. All students are required to complete 23 units for graduation: four in English and math, three each in foreign language, science, and social studies and two each in physical education, visual/performing arts, and academic electives. A semester course in religion and 76 hours of community service are also required. Advanced Placement and Honors courses are offered, and there is an internationally focused course of study through the Global Scholars Program. Our faculty has an average of 18 years' experience in the profession, 25 percent of the faculty identify as people of color and hail from more than 10 countries, and more than 70% hold advanced academic degrees.

THE EVOLVING VISION

In the last three years, our spaces and processes have evolved through many iterations and testing, much like the design process itself. Overall, we are developing a technology, design thinking, and making curriculum that begins in the Lower Division with basic skills and concepts in a MakerSpace. The curriculum then utilizes and expands upon those skills in the Middle Division years in the Elder Family Digital Lab and Smith Fabrication Studio. In our Upper

Division, the Best Design Studio and Lasher Technology Center provide a place and opportunity for advanced multimedia and video production and programming skills. This concept will then culminate in a capstone course for graduating seniors, which focuses on the culture and experience of the design process. Our classes are taught in spaces that are designed for long-term, multi-functional use that are ready to adapt to the vision of our program.

Though creating and making have always been a part of our curriculum, Berkeley is not primarily a project-based school. We do, however, realize the critical importance of hands-on learning and creating while teaching the design process (Dym, Agogino, Eris, Frey, & Leifer, 2005). In 2014, Berkeley Preparatory School's Headmaster, Joe Seivold, tasked members of the school with determining a deliberate and thoughtful process of how design thinking, along with MakerSpaces, STEAM and project-based learning fit into our existing school culture and curriculum. One goal of design thinking is to teach our students to be independent and creative problem solvers. Those who see difficulties and problems as challenges and actively look for creative and innovative solutions are people who make a difference in the world.

To begin the research, several administrators and teachers visited the Tonbridge Design, Technology and Engineering school in Kent, England because of a personal connection that an administrator at Berkeley had with the program's director. The visit was intended to help Berkeley decide how to develop its own program in terms of space and curriculum. Teachers attended the Invent to Learn conference (see https://inventtolearn.com/workshops/) and the workshops led by Sylvia Martinez and Gary Steger to expand our knowledge of personal fabrication and physical computing. The teachers also attended the local Tampa HackerSpace for software and hardware training (see https://www.meetup.com/Tampa-Hackerspace/members/108028552/), and visited the downtown library, The Hive, for software training and room design layout ideas (see http://www.hcplc.org/hcplc/services/hive.html).

Some of the online resources we used are listed as follows:

- IDEO's Design Thinking Toolkit: https://designthinking-foreducators.com/toolkit/
- Invent to Learn book authored by Sylvia Martinez and Gary Stager: https://inventtolearn.com/buy-the-book/
- MakerSpace Playbook: http://spaces.makerspace.com/
- Youth MakerSpace Playbook: http://makered.org/wp-content/uploads/2016/10/Maker-Club-Playbook_Young-Makers-Jan-2012-6_small.pdf
- Zero to Maker: https://www.makershed.com/products/zero-to-maker

Our design thinking vision is still evolving, but our overall goals are to:

- expose students to how designers think, giving them skills to empathize, visualize and design;
- give students the skills and confidence to bring an idea to life; and
- allow students to practice creating, making mistakes, taking risks and building confidence.

For our scope and sequence, the guidelines are desired skills and expected performance:

SKILLS

- Tool and/or technique (this may involve multiple techniques with the same tool).
- Repetition of tool and/or technique, with scaffolding grade by grade.
- Fluency with tools and/or techniques.
- Problem-solving.

PERFORMANCE

- Creativity with tool and/or technique.
- Brainstorm and sketch ideas.
- Using multiple tools.
- Multiple solutions to the same problem.
- Ability to problem-solve.

LOWER DIVISION MAKERSPACE: BUILD SKILLS AND CONFIDENCE

Tamarah Gal Henderson, the Lower Division Technology/MakerSpace Coordinator, began in the Technology Department, creating the technology integration curriculum in the lower division and bringing a 1:1 iPad program to prekindergarten through fifth grade. Tamarah created the first MakerSpace in Lower Division in 2014, and is working on developing the design thinking curriculum for the division and school. Tamarah's classroom is the Lower Division MakerSpace.

Design of the Space-Flexible, Open and Storage, Storage and More Storage

In Lower Division, our first MakerSpace (2014-2015) was in a shared space with learning specialists. In-progress project storage was extremely limited, supplies were on carts or tucked into cabinets and workspace had to be cleared after each session. Because the space was shared, some work had to be done in the classrooms, which meant transporting a wide variety of supplies and projects on carts. Having a dedicated space is paramount to a successful MakerSpace. The lack of storage space made it difficult to store and access supplies and many items were not used. With no room to store in-process projects, this limited the scope of what students could work on and how much time they could spend on projects.

In fall of 2015, we moved into a dedicated, large corner classroom with lots of natural light. We found out that this classroom would be available in April of 2015, and our furniture and special projects budget requests were due the same month for the following school year. Working with our Steelcase representative, with research and resources on flexible learning spaces ("Space Design for Active Learning Classrooms – Steelcase," n.d.) and designing multiple work areas ("Active Learning Spaces," n.d.), we quickly came up with a design plan that we thought would work. We left most of the room open, with only two permanent storage cabinets. Some walls have permanent features, such as the Lego, Velcro and a green screen wall. All furniture in the space is flexible and/or on wheels. For example, Steelcase flip top nesting tables allow for open floor workspace; Hokki stools allow for children's natural desire to move and tables adjust to standing height; IKEA Kallax bookshelves (horizontal and on wheels) is storage for in-process work; and Smith System Cascade mini-towers on casters hold the majority of supplies. We started with four towers and added two in the following year. We could easily use more to house supplies that are in the permanent storage cabinets and a storage closet nearby. Having the supplies in a clear visible container allows easy access and visibility of inventory. Two towers house supplies that students need to ask permission before use, otherwise students have easy and regular access to the drawers. We can also put those supplies that are being used for a particular project in one tower separate from the others.

Because the furniture is so flexible, the setup depends on the students and the project. First graders braiding or sewing might lie on the open floor, with tables flipped up to the sides of the room. Second graders building country monuments might need two tables put together for their team to work collaboratively in building. Third graders working on precise placement of conductive wire to create a switch might stand at tables. Stations can be particular to tasks, such as hot glue, paint, paper cutting, and computers or iPads.

FIGURE 1. Students measuring for a sea turtle shell prosthesis.

Factors Determining the Use of the Space and Curriculum

The Lower Division Technology/MakerSpace team meets with grade-level teachers to look at their curriculum for project-based learning opportunities. Our specialists are also included in the final project decisions to fully integrate the student's learning. The chosen units are already units within the classroom curriculum, so teaching lessons do not change but are supplemented, and final assessments include grading on the actual projects, the process of making and collaborate work, if applicable. One challenge was that there is no scheduled classroom time for MakerSpace. With administration's approval, we use computer lab time (once a week for 45 minutes), or if we are working with a specialist, we use their scheduled time with the students. This year, we have implemented a new model, where we take 10 of the students (half of the class) for project time, leaving the teacher with a smaller group to conduct reading or writing workshops. We also allow students to come in during recess to finish up any projects they are working on. Each grade level has these types of projects that tie directly in with a current classroom or specialist's curriculum, yet allow students to create their own vision.

For example, our first graders visit Winter the Dolphin, a local "celebrity" who was fitted with a life-saving prosthetic tail fin. Before their field trip, students learn about orthotists and prosthetics, and at the Clearwater Marine Aquarium, trainers provide background on how they finally settled on a design for the tail. Upon their return, students created

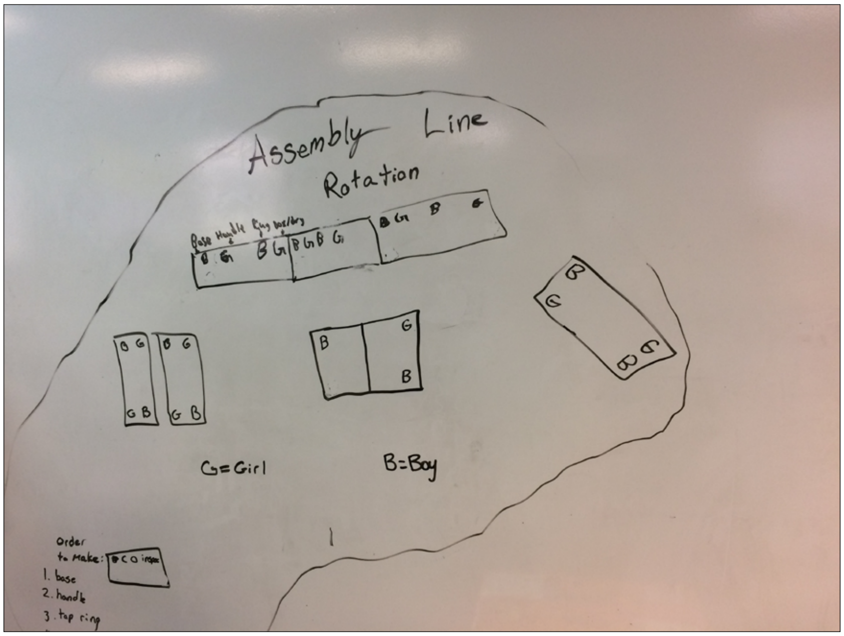

FIGURE 2. Assembly line plans.

FIGURE 3. Video of assembly line production.

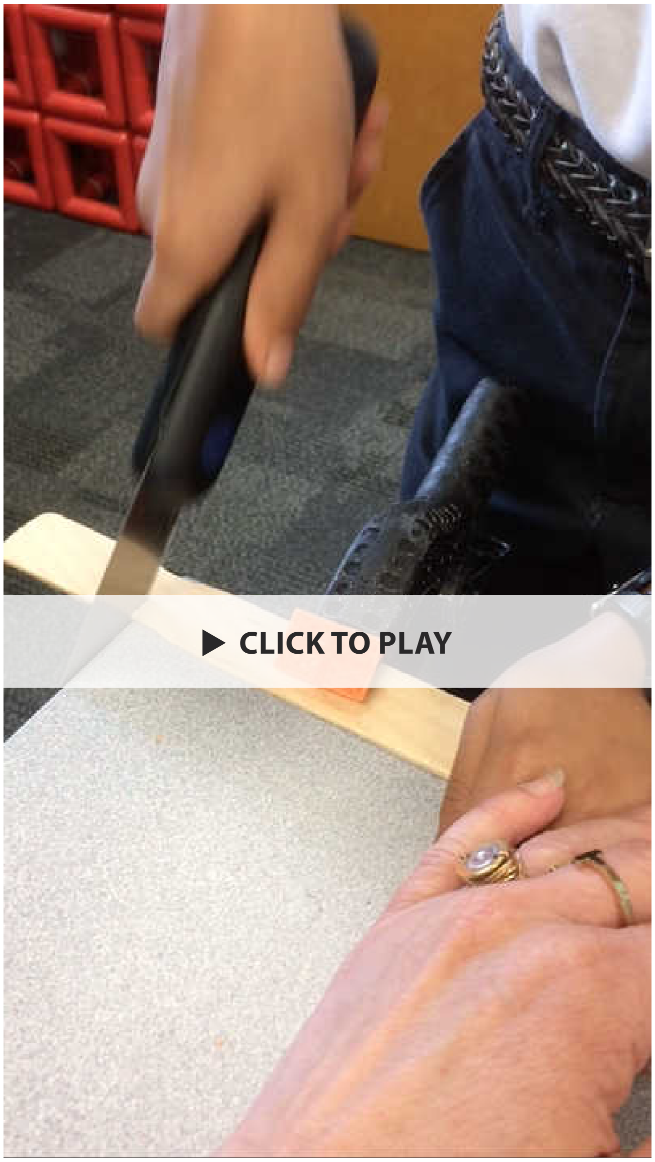

FIGURE 4. Video of student sawing off ends of paint sticks for the product.

and—humanely—attached prosthetics to stuffed animals who have been injured. This multi-disciplinary project allows students to: sketch their animals and create a mini-prosthetic add-on (art) and study animal movement and adaptation (science). This also aligns with the first introduction to the design process (IDEO, 2012, p. 15). Students empathize with the injured animals; they research why the animal needs the missing part; they brainstorm and sketch out a prosthesis and list the supplies they will need to create it; they create the prosthetic and attach it to the animal; and they reflect on what they would have done differently in student blogs (see Figure 1).

By fourth grade, the design thinking process is more structured ("Nueva Design Thinking," 2015). Students study basic economic principles for entrepreneurs before visiting

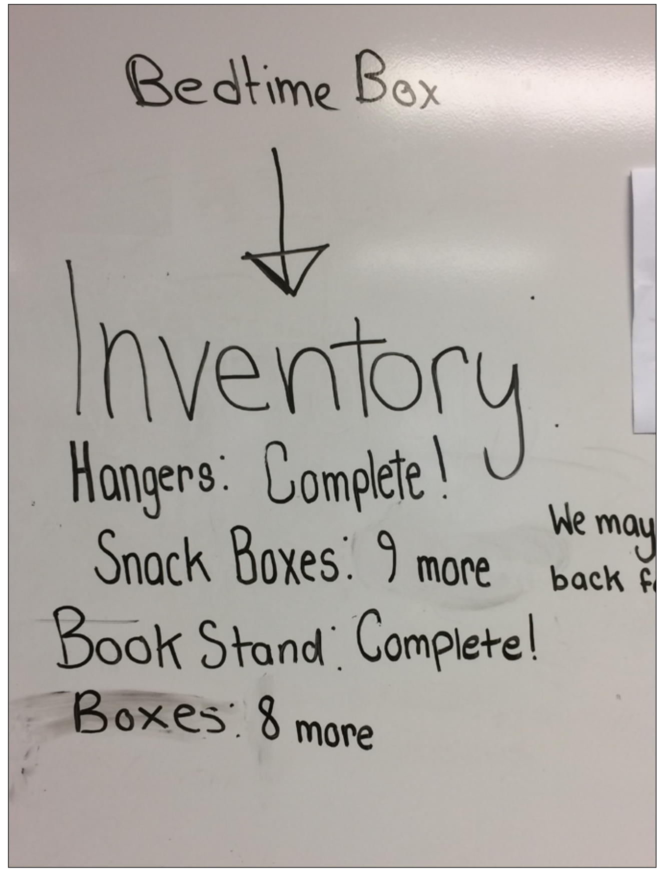

FIGURE 5. Updated work plans.

Junior Achievement of Tampa Bay's JA Biztown, a mini city simulation (see http://jatampabay.org/ja-biztown). Each student brainstorms to come up with an original or substantial modification of an existing product. In fourth grade, each student prototypes that product and comes up with a print advertisement. In fifth grade, the students decide on—by designated table groups—one product to prototype. In those groups, students create the prototype, refine the cost and pricing of the item, and create a print advertisement and a video commercial. Each of these groups then "Shark Tank" pitches to the rest of their class and let them test out the products. Students then vote on the top product per class. The top products are shown at our Lower Division convocation, and all Lower Division students can purchase these products, using canned food as currency. We then donate the food to our local food pantry. The winning invention teams determine an assembly line production process to mass produce the products that they and their classmates implemented. Then they create directions if needed and package the finished products, delivering them to their satisfied customers (see Figures 2, 3, 4, and 5).

The learning that happened for students and teachers as we rolled out this project was extensive. Social skills such as collaboration and teamwork evolved along with individual responsibility and self-troubleshooting. However, we found that we had to refine the rubrics for the print and video advertisements and mass production process to guide the students and allow for additional time for those wanting to put forth extra effort. As we became more stringent in our requirements for the product to be original or a substantial modification, a few students simply could not come up with ideas that had not already been created—our criteria was that it could not be found on Amazon, or a similar mass market shopping site. We had volunteer students come in to help us develop a creativity lesson, using the Extraordinaires Design Studio Deluxe tool (see https://www.extraordinaires.com/shop/the-extraordinaires-design-studio-deluxe) and the SCAMPER technique ("A Guide," 2015). Next year, we will brainstorm in small groups using these techniques before we ask students to submit product ideas.

Future Goals for Lower Division

With the increase in technology use in younger children, fine-motor skills are disappearing (Mikulak, 2014).These skills are critical for building confidence and resilience and promote creativity and problem solving when mastered. By developing scissor, tying, and sewing skills, introducing robotics, circuitry and simple building and modeling, we hope our students develop a design mindset that gives them the confidence that their ideas can change their world.

In our throwaway culture, children miss the opportunity to try to fix things by taking them apart and putting them back together. Our hands-on learning shows how things work, forming a basis for ideas on how they can create things. Our curriculum includes projects that take apart, rebuild, and then build from scratch, simple to complex objects.

SKILL	PERFORMANCE	TOOLS
SPATIAL REASONING—LOWER Students are: • Comfortable with 2-dimensional objects • Familiar with how 2-dimensional drawings will look 3-dimensionally • Proficient working in 3 dimensional CAD manipulation	Students can: • Draw reflection of part of an object • Draw symmetry of part of an object • Can recognize rotation of an object • Can identify parallel and intersecting lines and segments • Can build 3 dimensional geometric shapes • Can accurately draw polygons • Map route on paper map when given starting and end point • Compose objects in a 3 dimensional program • Create objects in cardboard • Can measure accurately • Plot coordinates on graph	• Puzzles • Geoboards • Tangrams • Nets • Paper maps • Makerbot • Printshop App • Shapemaker • Makerbot • 3D printer • Tinkercad
SPATIAL REASONING—MIDDLE Students are: • Proficient in estimating measurements • Proficient in how 2-dimensional drawings will look 3-dimensionally • Comfortable working in 3 dimensional CAD program	Students can: • Estimate the center of any given length, without using standard measuring tools • Understanding the diagonals of a piece pass through the center of the piece • Know multiple mathematical solutions to problems • Take a 2D drawing to cardboard and then to wood • Draw a 3 dimensional object	• Yardstick • Ruler • Measuring tape • Any straight line object • Cardboard • 1/4 in. plywood • Bandsaw

TABLE 1. Scaffolded curriculum example.

FIGURE 6. The first day of OpenLab in the borrowed science classroom. The image reflects the level of interest students had in making these ideas a reality.

As we refine the curriculum, we determine how design thinking skills can be added appropriately and purposefully. Our ongoing curriculum includes skills and concepts that are scaffolded, so that students are prepared to enter middle division with a greater sense of their capabilities, and therefore more prepared for open-ended and higher fail-risk activities. For students with a passion for making, projects that are more open-ended are offered in after-school clubs.

Our growth opportunities are in creating a scaffolded curriculum for all skills and activities (see Table 1). Building these skills will take some time to even out the competency level of students within each grade level. Establishing rubrics for collaboration and processes versus projects is an ongoing process and using these assessments in place of tests or writing assignments requires a joint effort with teachers and administrators. Besides building skills and vocabulary for the design process, our main goal in the lower division is to instill a sense of risk-taking and the ability to take an idea from paper to prototype in their own way; that there is no "right" answer to these projects. Design thinking applies to all aspects of our lives and exposing our students early to developing this mindset will establish this as a natural way to enhance any task.

MIDDLE DIVISION: INCREASING SKILLS AND TAKING RISKS

Elder Family Digital Lab

Meghan Campagna has a background in History and technology use in education. She moved from being a History teacher to Technology Integration Coordinator for Berkeley Preparatory School's Middle Division in 2014, and since then she has been working with teachers to incorporate technology into classes in innovative and meaningful ways. As Meghan's interests have increased in the STEAM and Maker Movements, she started and has been building a program to encourage students to explore their interests in tinkering, making, and building with electronics and technology. She looks forward to continuing to bring design thinking principles into all areas of her work. Aside from her history classes, Meghan's classroom is the Elder Family Digital Lab.

Design of the space: Allowing for growth of the program to determine use

In Middle Division, the maker movement concept has truly grown from the ground up. As the technology coordinator moved into her position in the fall of 2014, she had many conversations with the Middle Division Director about the potential for the position not as just faculty support, but also providing opportunities for student engagement in interests beyond what they have found in the traditional classroom setting. From these conversations, the OpenLab maker concept began in the spring of 2015. We offered students the opportunity to design, create, and build through the use of supplies housed in a 50-gallon rolling storage container that was rolled to a classroom once a week for student use. Students were then able to sign up during their flex period to come in and make things, using materials such as Raspberry Pi, littleBits, and Lego Mindstorms (see Figure 6). Because there was no home for the space and it was just the materials that made it what it was, everything had to be set up and torn down between meetings. There was no "space" inasmuch as there was an idea.

Because of the interest that was shown by students in the beginning stages of the program, the technology coordinator was given a small vacant classroom. This classroom was not designed with the intention of hosting a maker program, but because of the multitude of storage available, it became perfect for the temporary home of the maker program. As a result of having a semi-permanent space, more students continued to show interest in using the OpenLab and a new robotic elective called First Lego League was offered. During this year, the Elder Family Digital Lab was in the design stage, and the Middle Division Director and Technology Coordinator were able to sit down and look at the requirements for the new space.

The Middle Division Elder Family Digital Lab is a brand new space that opened in the 2016-2017 school year for use

FIGURE 7. The Elder Family Digital Lab's open layout: Ample floor space and flexible furniture provide the perfect template for teachers and students to set up however they need for that particular class period.

by all students and faculty. The space was left intentionally flexible, and what is currently setup is still being shifted as the year progresses and it is determined how teachers and students will use the space moving forward (see Figure 8). On one end of the room, there is a green screen with iPad stands set up for students to film using various backgrounds related to their projects. Along one of the long walls are countertops with stools for students to sit at to use the 20 MacBook Pros that are housed in the space. On that counter sits a MakerBot 3D printer. On the other long wall is a standing countertop for student collaboration and project work. There are also two iMacs loaded with InDesign, Photoshop, Final Cut Pro, and other software that becomes cost prohibitive for student laptops. On the opposite end of the room from the green screen, there is the Lego Robotics table that is used by the First Lego League. There is also a robot cage for the Vex robots utilized by the science classes. There are four UXL half circle folding, nesting tables that can be used for students working and raised to standing height but also rolled out of the way when students need the open floor space. There are two large Smith System Cascade mini-towers storage cabinets for all of the consumable supplies that students use on projects. The storage cabinets house such things as fabric, thread, and sewing supplies for electric sewing projects; Raspberry Pi and Arduinos for tinkering; and littleBits for prototyping.

As we continue to move forward with developing the technology integration and design thinking curriculums in the Middle Division, we will be able to add more to the space to make it fit our needs rather than making our program fit our space.

Factors determining the use of the space and curriculum

There are two different ways that the Elder Family Digital Lab is used, and each way provides its own opportunities and challenges to the development of the design thinking and technology program at Berkeley. The first, and main, way that the space is used is by teachers and students during their class periods. At the Middle Division Director's directive, It was determined at the beginning of the year that each teacher would use the Elder Family Digital Lab one time per semester for the first year of the space. This has been both a great success, and also a challenge in the development of the program in Middle Division. Teachers meet with the Technology Coordinator to determine what element of their curriculum could best be restructured or brought to life by the use of the Elder Family Digital Lab. Once a project or idea is determined, the teacher reserves the space on a Google Calendar, and the technology coordinator and teacher decide who will bring what supplies for the project. This has been a success in the sense that the lab has seen an incredible variety of projects and uses over the course of the year. However, it has been a challenge because there have been times that project ideas and desire to use the space have overlapped, thus making it seem as though getting to use the space is not worth the effort. Additionally, there is no designated person to manage the space and provide support for teachers and students every period—which is one hope for the program going forward.

The projects that students have completed in this space over the course of the school year have been incredible to experience. For example, sixth-grade students in their robotics unit in science were able to use the space to build, program, and run Lego Mindstorm EV3 robots. Students learned steps to program the robot and also how to build using several motors and sensors. As the unit progressed, students used mazes taped to the floor to iterate their designs and programs. The excitement in the room was palpable as robots made accurate movements and picked up objects along the way. The frustration in the room was also real when students could not figure out why the robot was not doing what the program said it should do. The learning that occurred was visible as teachers and students together problem solved and ultimately accomplished missions set up by collaboration between the science teacher and technology coordinator.

Building on the Computer-aided Design (CAD) principles that are further taught in sixth-grade science, seventh grade Honors Pre-Algebra students came to the Elder Family Digital Lab this year to explore and further understand 3D figures. Because teaching 3D figures on paper in 2D is not an effective way for students to understand surface area and volume (it provides a spatial challenge for students), the math teachers and technology coordinator worked together

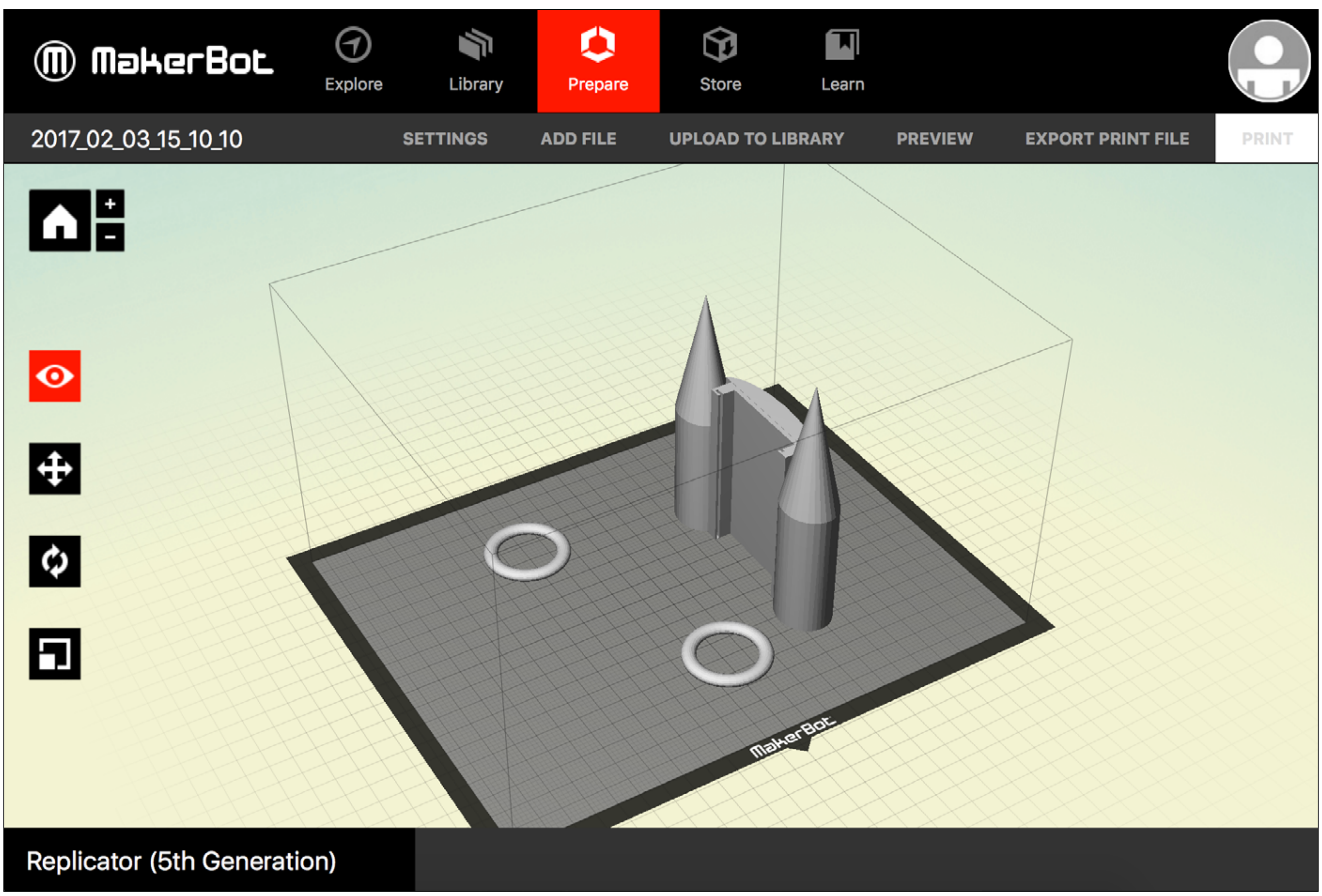

FIGURE 8. A screenshot showing one of the designs a student created from scratch in 123D Design to create a Tetris game. Measurements were done in the program, and Tetris-style pieces were also designed and printed to fit into the center part of the game behind a piece of plastic that served as the frame.

FIGURE 9. Two students testing a program written to attempt a mission on the First Lego League table.

to develop a project that would use a variety of materials and require students to build 3D figures, then measure their surface area and volumes. Some students opted to design figures in 123D Design or Tinkercad, then print the objects using the MakerBot Replicators, while other students chose to build their figures using material such as cardboard, plastic, and pipe cleaners (see Figure 8). Design thinking principles were used as students drew their figures in 2D, drew the nets of the objects, and then sketched how they would create them in 3D. Students further developed skills related to design as they realized the importance of proper measuring and scale. When students joined 3D printed objects to objects they had built, there was some trial and error with proper measurements.

In addition to being used by teachers and classes to highlight and add to the curriculum in the traditional disciplines, there are several clubs and elective classes that use the Elder Family Digital Lab as their home. Three of these clubs and electives are OpenLab, First Lego League, and Newspaper Club. The principles of design and engineering can be seen at any point during one of these meetings, but a few can be highlighted here.

One student in OpenLab has been focused and dedicated to working for the last two years on a cell phone built out of a Raspberry Pi. Through incredible determination, the student and the technology coordinator have worked through a myriad of challenges to the point that the phone has almost reached completion. To say that there have been multiple iterations would be an understatement. Skills that have been learned in the process of the creation include soldering, basic electrical systems, writing and executing code in the terminal, and microcomputing.

In the First Lego League, students compete in a year-long competition that demands that they build a robot to complete any of twelve missions on a robotics table. Students must use sensors and motors to accomplish these goals within a strict time limit (see Figure 9). The club also places focus on skills like leadership, teamwork, and gracious professionalism. In the two years that the club has existed for students in Middle Division, we have come a long way in developing a curriculum to ensure students understand the processes needed to complete the various tasks.

The Newspaper Club uses the iMac computer and InDesign to create their finished products. Students learn the intricate software and use it to achieve the look and feel that they desire for their printed newspaper. Along the way, they find challenge in using the software but also in deciding what their newspaper will look like.

Throughout the many uses of the space over the course of the year, it is clear that the program has grown an incredible amount in the three years that it has existed. Though we are still working on a more formal scope and sequence and scaffolded curriculum, the current program in place show how important a designated space is. As explained in the Lower Division MakerSpace section, skills and concepts even beyond the hopes of the teachers have been extensive and apparent. We know that as we continue to grow, we will see continued improvement in our project and final products.

Future goals for the space

As has hopefully been made clear, we consider being where we are right now a work in progress—though we have made so much progress already. Some of what we were hoping to happen over the course of the next few years has already begun to happen, as teachers and students are using the Elder Family Digital Lab to enhance their curriculum and add projects that bring learning to life. It has also given independent thinkers a space to come and brainstorm ideas and bring them to life.

Just as the space has had two different paths in how it has been used so far, the goals for the future take shape in those two ways as well: (a) technology and design thinking integration into the classroom and (b) curriculum—and also independent exploration—options for students beyond the traditional classroom model.

In terms of integration, the goals for the future include, just as mentioned for Lower Division, a scaffolded curriculum for both maker concepts and educational technology concepts. Though there has been some organic scaffolding of skills as teachers and the technology coordinator have worked together, the goal for the future is to ensure vertical alignment to both confirm instruction of skills but also build on those skills as students advance through their classes. It is the hope of the technology coordinator that this curriculum will be put into place to give teachers the opportunity to find places that various skills fit best into their own curriculums. As this is put into place, this will help us complete the setup of the Digital Lab with consumables, furniture, and organization to best fit the needs of the students and teachers who use it.

As for the clubs and independent exploration opportunities, the goal is to make the concepts discussed here approachable. Though some students inherently understand that they are interested in exploration, making, building, and creating, many students do not have a direction or goal for that making so do not know where to go if not given a set of ready-made opportunities. This has been the biggest challenge for the OpenLab concept, as students who have their own ideas do not want to be told what to do, and students who do not know what to do want to find a set of instructions to create a final product that fits their own desires and interests. Catering to the individual needs and interests of the 15-20 students who have signed up for OpenLab in the past has been a huge challenge and has led to an inability to serve the needs of anyone because of trying to meet the needs of everyone. As this program continues and develops, we want to find a way to mentor students to create what they wish to create, but also teach them the skills they will need to accomplish those tasks. In a way, this requires a curriculum of its own. We hope to further harness the opportunity that this can provide to students in the Digital Lab.

Smith Fabrication Studio

Peter Vogel has primarily worked in the fields of architecture and furniture design but also has spent a great deal of personal time working as fine art sculptor and painter. In the years since completing his Master's degree in Architecture from the University of California, Los Angeles, Peter has worked part-time as adjunct faculty at several small colleges in the Los Angeles area. He taught architectural drafting and woodshop at Beverly Hills High in the 2000-2002 school years, but found that the traditional curriculum expectations did not provide students with skills that seemed most necessary for real world success outside of the traditional trades. When the opportunity arose to work as part of a larger team to develop and evolve a truly integrated STEAM and Design Thinking Program at Berkeley Preparatory School, he took it! As the Middle Division Design Arts Teacher, he is delighted, daily, by the progress Berkeley has already made towards its goals, and most importantly by the amazing work achieved by his students. Peter's classroom is the Smith Fabrication Studio.

Design of the space

Our Middle Division Smith Fabrication Studio is located in a newly remodeled space that joined four previously existing classrooms into an amazing, and very flexible 3,000 square foot studio. The most exciting part of the space is 1,000 square foot machine tool room containing professional quality woodworking machinery and a full dust collection system. These tools allow our students to build both prototypes and high quality finished objects.Though we are currently using all of the space, we have already decided to add metal working tools in the near future. The addition of these tools will require additional electrical circuits and some reorganization of existing work and storage areas. Sixth through twelfth-grade students have the opportunity to develop their skills over time and without limitation (see Figures 10 and 11). Cut into one wall of the space is a large roll-up door, which was added to the early building plans so that larger and more complex projects, like a solar car, become possible.

Evolution of the design

The design of a new space, much like the design of a new program, is often far from linear and the goal is often less clear than might first be imagined. As building construction timelines are long, and Berkeley was planning a remodel of existing facilities, necessity required that the preliminary architectural programming and schematic design of the future fabrication studio begin early. Thus, the process began with an educational goal, but without a precise determination of the equipment to be used in the final space, a defined curriculum, or someone to teach in the space. Architects and our Middle Division administrators initially decided that one-half of an existing 3,000 square foot building that housed four classrooms would be given over to the fabrication studio. After the instructor was hired and long-term program goals were more clearly developed, it became apparent that the original 1,500 square feet would not be sufficient. This caused some planning problems early in the process, because architects, builders, and budgets strive to make as few changes along the way as possible. It took some time to develop open communication between parties to make the needed accommodations. In the end, it was decided that the entire building would be given over

FIGURE 10. Eighth-grade students using the new woodworking equipment to mill rough lumber that will be used to make a chair.

FIGURE 11. Eighth-grade student using the table saw to cut milled lumber to exact size for a chair project.

to the studio. When the structural engineer examined the building, it became clear that although a wide-open space was the most desirable, it would not be cost effective. The compromise was to cut large openings in several of the walls. The resulting building remains divided into four distinct spaces, and each area has a distinct use. There is a machine room, a bench room, a mechanical room, and a storage room that can allow for one or two large projects to remain in place as they are being assembled. Each of these spaces is designed both to meet immediate needs while remaining flexible for the future.

It was necessary to choose the woodworking equipment early in the design process, as the electrical requirements of the building could only be calculated based on predicted use. The architects also wanted to know the exact placement of the equipment, so that they could complete an electrical plan. This makes sense from the architectural perspective, but it does not make sense when trying to allow for long-term flexibility. If the space was indeed to be one that we grow into and not out of, it would be poor planning to let the installed electrical panels and outlets limit future growth. In addition, the utility in our area supplies power to our campus at 204 volts, and almost all woodworking machinery is designed to run on 240 volts. The design of the electrical supply within the building became a significant challenge. After much discussion between the architects, contractors, and the instructor, it was determined that the first phase of construction would be completed without running power to specific locations, and that the building would have a power transformer to convert 204 to 240. The second phase and future phases of construction would then allow the electricians to install conduit as needed. With our stage two now complete, we still have an ample supply of power to support the addition of metal working equipment, and importantly we are not locked into what equipment we will use and where in the mechanical room it will be placed.

The machine room is the one space in the building where layout and equipment placement is effectively permanent. The layout took the most time and demanded the most attention to detail. We looked at the largest materials that would be practical to use, and the tools were placed accordingly. For example, most often the lengths of wood being milled are two or three feet long, but the space can handle four by eight-foot sheets of plywood as well as 12-foot lengths of lumber. Because we know that having a CNC milling machine is a goal but not a practical choice at this point, the machine room was laid out with space for a mill in the future.

All of the tools and equipment in the bench room are either very lightweight or equipped with heavy duty casters. It takes little time or effort to relocate work benches and small tools to accommodate differing classroom needs and often this space changes several times a day.

In the mechanical room, we currently have a 60-watt Boss Laser Cutter with an 18 by 30-inch cutting table. Two desktop computers can alternately control the laser cutter, and students learn the basics of 2D CAD and operation of the cutter itself.

In many ways, the restrictions imposed by the original shape of the building have become an asset. Having four distinct spaces groups material and tool types together, as well as defines assembly areas and safety zones. Students in the sixth-grade work with small bandsaws, drill presses, and some hand tools, but are never allowed into the machine room area. The future metal working space will be distinct from the woodworking equipment so that metal shavings and sparks are isolated.

Though we know what we have planned for this space over the next few years, we do not and can not know how technology, our curriculum, and most importantly the needs, desires, and abilities of our students will evolve over the next 5 to 10 years. As with any design project, we have an idea, and we are chasing that idea to its best possible solution. The Smith Fabrication Studio was designed from the beginning with the intention that it will continually evolve.

Utilization of the space

Students in our demographic are highly results-oriented and the question most often asked by them is, *"is this right."* The goal of the curriculum is to shift students' approach to learning away from following a fixed linear path to a right answer and towards a greater willingness to approach learning as a process of discovery. Students will learn to evaluate their own answers based not on what is written in the book, but rather on evaluating how well they used the available resources to achieve a stated goal. This is obviously not an easy thing for students to do and our curriculum is scaffolded to give students practice at applying skills learned to increasingly complex open-ended problems. The end goal is that a twelfth-grade student who has completed a successfully scaffolded Design Thinking program at Berkeley will come to his or her teacher with a statement like the following "*This is my goal, and this is the work I have done to date to work toward that goal. At the moment, I am currently stuck. I tried these potential solutions and they haven't worked. I know that there must be a solution. A couple of my friends had some good ideas but those didn't seem to work either. I've done my research and I can't think of any other approaches. I really want to accomplish this goal and I feel confident that I can, but I don't know what to try next. How would you suggest I proceed?".*

The goal of the Middle Division Design Arts program is to help students become more effective problem solvers; a mindset more than a specific set of skills. However, since we cannot solve problems if we have no skills to apply, projects are divided into two parts. There is a goal, and there are the craft skills needed to achieve that goal. The goal, or the

Design Challenge, is an open-ended problem that allows each student, or group of students, the opportunity to realize a unique solution and arrive at a unique "right" answer. The craft skills needed to achieve the goal are the Tool and Technique Vocabulary. When explaining Tool and Technique Vocabulary, this question is posed to students: "*When you are just two or three weeks into learning a new language are you able to tell a story about yourself?*" They all quickly realize that even if they tried, it would be a very short and not very interesting story. The question is why? The answer is that their tools and technique vocabulary in the new language is very limited. They have a story to tell, but nothing to tell it with. Having a shop full of tools is like having a dictionary in a language you cannot read. The object you want to make is like the story you wish to tell. Over time you slowly build up your language skills so that you can tell an interesting story and over time you slowly build your craft skills so that you can build increasingly complex objects. The analogy works and allows us to separate the safe and effective use of a tool (which does have a right and wrong answer) from what is made using the tool (which has a very wide range of right answers.)

A simple example of this is an introductory project done with sixth graders. The finished product is a small key chain tag. The Design Challenge is the graphic design of a logo using positive and negative space. The Tool and Technique Vocabulary skills are the safe and effective use of a small utility knife and an introduction to the laser cutter as a tool. We begin with skills the students already have (drawing and cutting with scissors) and add the new skills of using drawing as a method for exploring ideas, and using a small utility knife to cut paper. Students quickly learn to use the new tool, but are so excited to be allowed and able to use a utility knife that they very often fail to see that when cutting a positive shape a pair of scissors is most often the faster and more effective tool. This is an instructive part of the lesson, because part of improving our Tool and Technique Vocabulary skills is choosing the best tool for the job, and part of improving our problem-solving skills, is improving our ability to move between different skills while working toward a goal.

Currently the seventh-grade classes are working on a large-scale Rube Goldberg machine. This has been a really great project for a variety of reasons. To begin with, it is a direct example of a complex machine made up of many smaller simpler operations. We ask students to think about what happens when they turn the key to start the car engine. Our machine starts with someone throwing a ball at a target and ends with the goal of dumping a bucket of water on someone's head. All of the steps in between are both undefined, yet dependent on one another. Students work in small groups of two or three to imagine, design, and build a single action/reaction step (see Figure 12). An example would be a wooden car rolling down a ramp and lands on a teeter-totter which throws a ball. Students then need to learn the basic skills to build the ramp—which they can do effectively with a very basic level of craft. The first problem

FIGURE 12. Students testing component parts of a large Rube Goldberg machine.

arises when the car does not stay on the ramp but veers off halfway down. Once this is solved, they find that the car does not hit the teeter-totter with enough force to throw the ball. We can then look for, and test possible solutions to this problem. *"If we increase the weight of the car does that help? Yes, but not enough."* Each piece of the large machine needs to be imagined, built, tested, refined, and then likely needs to be adjusted to work with the next part of the machine. Students struggle most with the willingness to keep testing. They tend to stop with the first difficulty and look to the teacher to solve the problem. They also tend to think *"it does not work"* and start over from the beginning rather than try to analyze the specific problem. Learning to differentiate the part of even a simple system that does not work and correct that part, is hard to learn and therefore difficult to teach.

The hands-on building that our students now have the opportunity to participate in, as a result of this new facility is proving to be effective in this effort. Students are solving the problems, and as they learn new skills and test more options, they are demonstrating improved understanding. What is important to note is that they are beginning to use each other as resources in their search for solutions. As a caution, it needs to be pointed out that as students gain confidence, they tend to want to teach each other. In most cases, this is a good thing that we wish to encourage, but problems arise when students "teach" one another to use a tool. This is fundamentally unsafe, and so we are currently exploring ways to differentiate for students—what we want them to share with one another and what they must look to their instructors to learn. As in Lower Division, students' social skills, such as collaboration and teamwork, evolve along with individual responsibility and self-troubleshooting.

FIGURE 13. Upper Division students work on the basic mechanics of front wheel steering as they begin designing an electric car for the Electrathon America competition.

Factors determining the use of the space

The Design Arts program in Middle Division is just a year and a half old and has come a long way! It is driven by the idea that students of every age are creative, capable, and effective problem solvers. We believe that when students are given the opportunity and the right tools, they become active and engaged participants in their own education. Berkeley's Design Arts curriculum coupled with the new Smith Fabrication Studio provides our students the opportunity to explore the process of design thinking from idea to build form. Projects are based on the teaching of concepts, rather than on the technique of making. This space is not limited to any given set of materials or methods. Because of its size and flexibility, we can be doing woodworking in one part of the studio and repairing and rebuilding bicycles and motorcycles in another.

The craft of making takes practice and time to develop, and the methods of making change at an accelerating pace as the tools we use become more automated. What does not change over time is the power of our imaginations. When we couple our students' imaginations with design thinking skills, we give them the ability to be powerful open-ended problem-solvers.

Future goals for the space

As with our other spaces, some of our future hopes are already happening! Recently a seventh grader wanted to create—as part of a toy-design project—a palm tree's flexible trunk. She remembered seeing a flexible snake toy and was able to picture how the toy worked. With a bit of guidance, she understood how the CAD program allowed her to quickly draw a long narrow rectangle, and how our Boss Laser cutter could inscribe into quarter-inch plywood a sequence of accurately placed repetitive lines. She went from an idea to a working prototype, with the process taking no more than twenty minutes.

It is our hope that as students move through an integrated K-12 curriculum, they will take the initiative to pursue self-directed projects. This goal is already becoming a reality. As examples, two eighth grade students recognized that they could make their history project special by depicting their ideas through a three-dimensional portrayal of an old sailing ship. An eleventh-grade physics student recognized that by combining his CAD skills with our laser cutter's capabilities, he could craft precise pieces for a project that his peers were constructing with scissors. Theater Arts students used the laser cutter to make shadow puppets needed for their recent musical. Most exciting, a group of engineering students who saw what is possible in the space have begun the process of designing and building an electric car that they plan to enter in local Electrathon America competitions (see Figure 13). The students working on the electrathon are coming in before school two days a week because it is the only time they have in otherwise very busy schedules. They are taking the initiative to pursue their passion and guide their own learning. Projects of this scale and complexity simply did not have a place to evolve before the completion of this space.

Our desire is for Middle and Upper Division students across disciplines to continually use our design arts spaces, fostering abstract learning and hands-on exploration. A physics text can teach light refraction, but when you couple the reading with pinhole camera construction and a discussion of photography's influence on the Civil War, you magnify understanding and provide a multimodal learning experience. Our science department chair, an eighth-grade history teacher, and our design arts teacher are currently developing such a project.

Encouraging self-directed, lifelong learning is our goal. Students need the knowledge and skills to solve increasingly complex problems collaboratively. Methods of work and tools and techniques will change over time, and we aim to teach through our design arts curriculum nimble learners who can adjust and thrive.

Iterations and realizations

In the past year, there have been projects and goals that have not worked as hoped or planned, but we do not see these as failures. We regularly work to teach and remind students that in the process of finding a good solution, the ideas and attempts that do not yield immediate success are to be expected and provide opportunities to learn. One of the biggest hurdles we face at this early stage is our students stopping and not moving forward because one piece of what they are doing does not work as desired. They continually question *"is this right"* or make statements such as *"I'm not good at . . . ."* If we wish our students to become successful problem solvers, we must always model to our students the behavior and actions we would like to become their habits and practice. To use the word "failure" is using language that is not conducive to the space and our goals.

Another daily hurdle faced is providing safety oversight that individual students need as they develop basic skills, while keeping the much larger remaining group on task without direct supervision and instruction. We have a possible solution to this problem using our existing Writing Center as a model. If implemented it can transform a hurdle into an asset! In the Writing Center, upper division students work with middle division students as writing coaches. In the Smith Fabrication Studio, upper division students would become shop assistants. This would be a fantastic way to place students first in the classroom.

Perhaps our biggest hurdle is simply time. Our current rotating schedule allows students to have a large variety of learning experiences through their school week, but as a result, the amount of time they spend in Design Arts is quite limited. The time limitation has been an ever-present reminder to focus precisely on teaching the most important aspects of design thinking, and to continually revise and fine-tune the curriculum. The Rube Goldberg project comes from this thinking. Previous projects had the same goals but required a high level of craft to realize a successful project. Since students do not have the time in the seventh grade to both practice problem solving and develop craft, it makes more sense to build something which can be very rough or crudely made and still function. The success of the project is in the fun of watching it work!

UPPER DIVISION—COLLEGE PREP, ANDVANCED PLACEMENT, AND CAPSTONE

Upper division is where students can apply everything they have learned in lower and middle divisions, expand or focus on specific interests, and hone their skills. Besides the typical high-level academic courses found at most preparatory high schools, several courses have culminating projects that require creating. These include Honors Physics-Engineering, Pneumatics with Robotics, Computer Science, Digital Design, Computer Animation, Mobile Applications, Design and Technical Theatre, and Stage Design. Students create films for film festival entries (in the Best Multi-Media Room), design and create sets and costumes for in-house theatrical productions (in the Smith Fabrication Studio), design mobile applications submitted to the Apple App Store (in the Lasher Family Design Technology Center), and compete in international robotics competitions. In the 2017-2018 school year, a capstone course will be offered to seniors that will take them from brainstorming, to product prototype, to testing and redesigning as necessary, to creating a solution to a relevant issue that exists in our world.

CONCLUSION

By design, our spaces support our current curricular needs and are intentionally flexible to support future learning goals. Because of these designs, we can continue the process of providing opportunities (curricular and co-curricular) for our students. Our scaffolded curriculum builds creativity, fortitude, and ability. Our learning goals apply real world challenges and provide opportunities for students to take risks and push themselves beyond preconceived limitations and expectations. As students come to understand and embrace the design thinking cycle, we want students to feel empowered to have a voice and make a difference in the world around them. As our motto states, "Berkeley puts people into the world who make a positive difference." If they can create things to solve real-world problems, students will understand new, powerful ways that they can make a difference.

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