CROSSING A CHASM ON CARDBOARD

A CASE STUDY FOR TEACHING MORE SUSTAINABLY

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PAPER ABSTRACT: With issues like climate change, pollution, deforestation, drought, extreme weather patterns, and a world population that is projected to reach 9.8 billion by 2050, there has been a strong push in industrial design education to teach sustainability to the next generation of designers. In order to teach sustainability, many schools utilize hands-on projects as an engaging way for students to learn and apply design principles but many of the materials used for the project prototypes are often not sustainable, or eco-friendly including blue/pink insulation foam, high-density urethane foams, foam board, MDF, particle board, putty fillers, plastics, epoxies, adhesives, joint compound, primer, and non-eco-friendly paints. Is there a way to teach sustainable design effectively using only sustainable or more eco-friendly prototyping materials? This paper describes a case study where a 2nd year industrial design studio was tasked with designing and building a personal watercraft made only from corrugated cardboard (no tape, glue, paint, or fasteners) which had to transport the student across 75 ft. (width of a pool) of water without sinking. The successes, failures, and learning outcomes are shared with the hope that others would build upon this learned experience.

Keywords: Sustainability, Materials, Eco-friendly, Industrial Design, Education

1. INTRODUCTION

According to the UN, the world population is projected to reach 9.8 billion by 2050 (UN, 2017). With this increase in population comes the potential for water and food scarcity, an increase in energy usage and pollution, and an irreversible depletion of natural, non-renewable resources. Fossil fuels such as coal, oil, and gas are the largest contributor to global climate change, accounting for over 75% of global greenhouse gas emissions and nearly 90% of all carbon dioxide emissions. The world is warming faster than at any point in recorded history and is causing extreme weather patterns and drought, which poses many risks to all forms of life on Earth (UN, 2022). Due to these issues, there has been a strong push in industrial design education to teach sustainability to the next generation of designers. In order to teach sustainability effectively, many schools utilize hands-on projects as an engaging way for students to learn and apply design principles but many of the classic prototyping materials used for the projects are often toxic, and not sustainable or eco-friendly including blue/pink insulation foam, high-density urethane foams, foam board, MDF, particle board, putty fillers, plastics, epoxies, adhesives, joint compound, primer, and non-eco-friendly paints. Is there a way to teach sustainable design effectively using only sustainable or more eco-friendly prototyping materials? This paper describes a case study where a 2nd year industrial design studio was tasked with designing and building a personal watercraft made only from corrugated cardboard (no tape, glue, paint, or fasteners) which had to transport the student across 75 ft. (width of a pool) of water without sinking. The successes, failures, and learning outcomes are shared with the hope that others would build upon this learned experience.

2. LITERATURE REVIEW

2.1 THE CARDBOARD BOAT BOOK

Michael F. Hein, Professor at McWorter School of Building Sciences at Auburn University, first challenged his civil engineering students in 1982 to build a cardboard boat capable of traveling 100 yards along the shores of Lake Sammamish to teach principles of buoyancy and stability. Each student could only use a maximum of 36 square feet of 1/8”, single-ply corrugated cardboard to construct the boat, but paint, glues, and waxes were allowed. The self-propulsion device also needed to be made out of corrugated cardboard but not from the initial 36 sq. ft. of cardboard. There was no constraint listed as to how much additional cardboard was allowed for the propulsion device. The project assignment culminated in a first annual Engineering Tech “Sink-R-Swim Regatta”. David W. Friant, one of Professor Hein’s students, accepted the challenge and successfully crafted a cardboard boat which served as his initial inspiration for writing “The Cardboard Boat Book”, an illustrated guide to building a cardboard boat based on his original design for the class. In the book, Friant expands on his original design, “The Kayaker”, and gives detailed instructions on how to construct his design made from “21 pieces of ¼” , 275 lb. test, double wall, corrugated cardboard, ½ gallon of eco-friendly contact cement, one roll of paper drywall tape, and sealed with one gallon of eco-friendly waterproof coating.” (Friant, 2009)

2.2 BRIEF HISTORY OF CARDBOARD BOAT REGATTAS

The first documented cardboard boat project was assigned on September 25, 1962 by Davis Partt to his senior design students at Southern Illinois University. The requirements were: “1. Provide water-borne transportation for one person (yourself) for a distance of 100 ft. 2. User's clothing must remain dry. 3. Corrugated cardboard 275# test (furnished) must be used as a basic structural material. It may be supplemented by use of any other materials considered necessary.” (MacLaren, 2010) Since then, many schools and organizations have held cardboard watercraft regattas and races to teach design, engineering, physics, or just to have fun, however, the participants were allowed to use non eco-friendly supplementary materials such as duct tape, adhesives, and latex or acrylic paint/coating to construct cardboard boats and paddles. MIT has held an annual cardboard boat regatta for many years called “The Head of the Zesiger”, where students built cardboard boats and were allowed to use paper tape, and paint to race in a course laid out at MIT's Zesiger Center pool. Some of their students used foam kickboards as paddles (MIT, 2013). Cambridge University holds an annual end-of-year cardboard boat race where the students can build their boats out of anything as long as the primary material is cardboard (Cambridge University, 2019). For propulsion, students can be seen using everything from canoe or kayak oars to pots and pans (Ryan, 2022). Many other schools allow the use of duct tape, and paint for their cardboard boat competitions including UA Little Rock (2022), Georgia State University

(2018), Southern Illinois University, Carbondale (2019), Henderson State University (2021), and Southern Adventist University (2023). In some competitions, kickboards or oars were allowed as propulsion devices and in some cases, whole boats were wrapped in duct tape and/or coated in latex or acrylic paint/coating for waterproofing.

2.3 JUST CARDBOARD VS. "MONSTROUS HYBRIDS"

Corrugated cardboard is one of the most sustainable prototyping materials because it is often composed of a relatively high amount of recycled content (70-100%), it is completely biodegradable, made from renewable resources, relatively inexpensive, and can be recycled up to 25 times (Bennett, 2022). However, when additional materials are adhered to the cardboard, it often makes the cardboard not recyclable because of how difficult it is to separate the materials. In their book, "Cradle to Cradle", Braungart and McDonough coined a term "monstrous hybrid", referring to "any product, component, or material that combines both technical and organic nutrients in a way that cannot be easily separated, thereby rendering it unable to be recycled or reused in either system." (Braungart & McDonough, 2019). The additional materials applied to the cardboard boats, especially the paints/coatings and the glues, create "monstrous hybrids" because it is very difficult and/or too time consuming to separate the paint/coatings, and glue from the cardboard to make it recyclable. Observing the excessive use of duct tape, paper tape, glue, and/or paint, led to this question: is it possible to construct viable cardboard watercrafts and propulsion devices without using additional non eco-friendly materials and avoid creating "monstrous hybrids"?

3. METHODS AND PROCESSES

To answer this question, 2nd year industrial design students were challenged to design and build flat-packable, cardboard watercrafts capable of keeping them afloat while traversing the width (75') of a University pool, using a maximum of three sheets of 4x8' C-flute (11/64" or about 4.4 mm) single-wall, corrugated cardboard. No tape, paint, adhesives, fasteners, or any other materials were allowed. Propulsion devices had to be entirely human-powered and could also only be made from the same c-flute corrugated cardboard sheets. The term "watercraft" was utilized intentionally instead of "boats" to encourage students to think outside of the traditional boat form. The cardboard sheets were purchased in bulk to save on overall cost, time, and transportation. Students were encouraged to familiarize themselves with corrugated cardboard, existing watercraft designs, ergonomics, physics of water buoyancy, joinery, cutting, and folding techniques. The prototyping process began with sketching and building half-scale physical models which were load-tested with a piece of concrete or a dumbbell in a small kiddie pool.

Figure 1. Load-testing half-scale cardboard watercraft prototypes.

The larger prototypes which did not fit in the kiddie pool were tested in a small nearby pond. Every prototype failed to stay afloat when a full load was placed on top of it. This was a sobering, but excellent learning experience for the students as they learned very quickly some of the critical problems in their designs. They learned firsthand about Archimedes' principle which states that “the buoyant force on an object is equal to the weight of the fluid displaced by the object.” (Encyclopedia Britannica, 2023) All of their learning from the initial half-scale test was utilized in constructing a full-scale prototype to test in the large University pool. Many of the students also failed to cross the pool with their first full-scale prototypes, however, once the first student crossed successfully, the rest of the students quickly tried to learn the key principles for success and created their own designs based on these principles. Since cardboard was the only material allowed, some students created cardboard fasteners to hold parts of their watercrafts together. The most successful students did additional testing and refining on their own time before the final presentation to ensure they could make it all the way across the width of the pool. The four week project culminated in a first annual cardboard watercraft regatta and competition with six different categories: 1. fastest, 2. lightest, 3. fastest assembly time (from a flat-packed state), 4. most aesthetically pleasing, 5. most style/flair, and 6. people’s choice. Each student was required to create a poster and IKEA-style assembly instructions to display along with their full scale prototype for the cardboard watercraft regatta.

Figure 2. First full-scale cardboard watercraft prototypes about to be tested in the pool.

Figure 3. The lightest watercraft, weighing 3.3 lbs.

4. CARDBOARD WATERCRAFT REGATTA

On the day of the regatta, students brought their cardboard watercraft in a flat-packed state and were timed as they assembled them to determine the winner of the fastest assembly time competition. The fastest assembly was 43 seconds, the longest was 16 minutes and 44 seconds, and the average was 4 minutes and 33 seconds. After assembling their watercraft, each student weighed their prototype to determine the winner of the lightest competition. The lightest was 3.3 lbs. or approximately one 4x8’ sheet of cardboard, the heaviest was 7.85 lbs. and the average was 5.08 lbs., or less than two sheets of cardboard. After all of the students finished assembling and weighing their watercrafts, a total of 26 students raced in pairs over the shallow (4’) section of the University pool so that students could simply stand up if they went into the water. The fastest crossing time was 26 seconds, the slowest was 1:14, and the average was 46 seconds.

Figure 4. Fastest watercraft crossed the width (75’) of the pool in 26 seconds.

5. PROJECT ANALYSIS

Overall, the project was a success. It is indeed possible to make cardboard watercrafts that can cross 75' of water without any tape, adhesives, or waterproofing paint/covering. By avoiding the use of extra materials, no “monstrous hybrids” were made and all of the cardboard utilized for the entire project was recycled, including the initial prototypes and the final regatta watercrafts, thereby minimizing environmental impact. Students learned that it is indeed possible to create products out of a single, more sustainable material, and still achieve the goals of a project. Constraining the project to only cardboard also encouraged students to focus more on creative problem solving and pushing the limits of the material.

The keys to success for those that made it across were: 1. the cardboard was folded in a way so that there were no seams where the water could enter into the watercraft, 2. the watercrafts displaced enough water volume to exert enough buoyant force (Archimedes' principle) to support the weight of the user and vessel, and 3. the bottoms of the watercrafts were rigid, stable, and strong enough to effectively distribute the weight of the user. The big question, even for the faculty members teaching the course, was if the cardboard would have enough structural integrity to be utilized as a watercraft when there was no waterproofing material such as tape or paint applied to it. Shockingly, even without waterproofing material, the watercrafts kept out water long enough to be utilized for the race. In some instances, the watercrafts were utilized for multiple races just for fun after the competition and they still worked. Some of the other project strengths include a majority 80.8% (21 out of 26 students) success rate for students crossing the pool, students learned the importance of failing fast and iterating rapidly, no students exceeded three sheets of cardboard- most used under two sheets, students practiced designing a product that is functional and beautiful, they learned how to design with constraints, they learned important physics principles, they developed their craft and design skills, and practiced creative problem solving. Any extra unused cardboard sheets were placed in the school's material resource room for students to utilize in any future school projects.

Some weaknesses of the project include a 19.2% failure rate for crossing the pool. Those that did not make it across the pool did not do adequate testing and make drastic enough changes/refinement in their designs to create viable watercrafts. They often did more subtle refinements but they needed to really rethink their entire approach. The students who were struggling were strongly encouraged to consider different approaches, but some students refused to change their strategy or did not have enough time to change it, and in the end, they learned the hard way why their designs did not work. This percentage will most likely be decreased in future classes because students often learn from the failures of previous classes. Another challenge was the varying weight of each student. Some of the heavier students were at a natural disadvantage because they had to design their watercrafts to support more weight than their lighter classmates. However, in the end, all of the heaviest students made it across the pool so it actually still came down to the testing and refining phases of the project. Another issue was that even though 80.8% of the students made it across the pool, some of their designs did not progress as much aesthetically once they developed a prototype that worked. Some of them did not have enough time to develop it further or they were afraid to make any changes to it out of fear that it would affect the functionality and/or integrity of their watercrafts. One last issue was that some students underestimated the amount of cardboard that they would need to make full-scale testing prototypes and ended up buying additional sheets which cost more per sheet than the initial bulk order and took time away from their prototyping.

Future opportunities for improvement or developing the project further include potentially extending the race distance to twice the length and adding a turning/reversing component where the students paddle to the other side of the pool, turn around or paddle in reverse for a total of 150 ft. 75 ft. was the initial goal since this challenge had never been done before at the school without tape or paint, but after witnessing how the watercrafts still worked after multiple races, it seems very possible for them to travel much farther before getting too waterlogged. The turning/reversing challenge would add an extra consideration for maneuverability and the extra distance would test the structural integrity of their designs. Since most students utilized less than two sheets of cardboard, future project constraints can be reduced down to utilizing a maximum of two sheets of cardboard instead of three to help reduce the amount of total material utilized. Since the average assembly time of the watercraft was 4:33, a maximum time limit of four minutes for assembly can be established to encourage students to make their watercraft as easy and fast as possible to assemble. Since all of the students weighed differently, another future competition could be the best strength-to-weight ratio or best pound-for-pound watercraft. Further tests could also be done in the future to determine how long it takes before water seeps into the interior of the watercrafts without any waterproofing. In the future, watercrafts could be left out to fully dry and tested again to understand the effect of repeated soaking and drying on the structural integrity of the cardboard.

6. CONCLUSION

Many industrial design educators would like to teach industrial design concepts and skills with more sustainable materials and processes but it is not easy given the toxic and/or non-eco-friendly nature of many classic industrial design prototyping materials including high-density urethane foams, blue/pink insulation foam, foam board, MDF, particle board, putty fillers, plastics, epoxies, adhesives, joint compound, primer, and non-eco-friendly paints. Cardboard is a relatively inexpensive, readily available, eco-friendly material in that it is recyclable and can be made with a high percentage of recyclable content, however, when combined with other materials such as duct tape, adhesives, and waterproofed with paint or coatings, it is no longer recyclable. The extra materials adhere so much to the cardboard, especially the waterproofing paint or coating, that it makes the materials virtually impossible to separate, creating “monstrous hybrids” and cannot be processed by most recycling facilities. More often than not, these monstrous hybrids end up only adding to our landfills. Cardboard boat competitions have been utilized by many schools and organizations to teach skills and knowledge or just to have fun- which are all good things, however, the ultimate end result after the competitions is still more monstrous hybrid additions to our landfills. This led to a question that this case study was designed to answer: is it possible to have the skills and learning benefits from cardboard watercraft competitions without the use of non-eco-friendly materials such as duct tape, adhesives, and paint? As this case study has shown, it is certainly possible and strongly encouraged. It is the hope of the author that schools and design programs which teach skills and knowledge through project-based experiential learning will utilize eco-friendly materials whenever possible to help limit the amount of non eco-friendly materials from reaching our landfills and oceans and to set a strong example for our students to be good stewards of our world.

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