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Will It Float? Iterative Design and Learning Through a 3D Printed Boat Design Challenge

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Abstract

This *evidence-based practice* paper details a hands-on design challenge for first-year engineering students aimed at fostering creativity, problem-solving, and iterative design thinking. Students were tasked with designing and 3D printing miniature boats capable of supporting maximum weight before sinking.

Motivation: The project integrates theoretical concepts of buoyancy with a practical application, allowing students to experience engineering constraints and iterative design.

Objectives:

1. Enhance understanding of buoyancy principles through hands-on learning.
2. Develop skills in computer-aided design (CAD) and additive manufacturing.
3. Cultivate iterative problem-solving and adaptability through multiple design refinements.

Practical Implementation: The project began with an introductory tin foil boat activity, transitioning to CAD-based design and 3D printing within size constraints to promote creativity and efficient use of resources. Students iteratively refined their designs over several weeks, testing them under increasingly challenging conditions, including still water and simulated wave action.

Assessment Methods: The project was evaluated through qualitative analysis of student interviews, design documentation, and performance metrics such as buoyant efficiency (weight held to boat weight ratio). Observations revealed that students progressed from maximizing volume to optimizing weight distribution and structural integrity.

This study underscores the value of structured design challenges in fostering engineering competencies, providing actionable insights for integrating similar activities into first-year engineering curricula. The paper offers practical guidance for educators to adapt this approach, emphasizing iterative learning and real-world problem-solving.

Keywords: Design process, Rapid prototyping, First-year engineering, 3D printing

1. Introduction

Hands-on experiences are central to engineering education, as they enhance theoretical understanding and equip students with critical skills for future careers. Iterative design, a key aspect of this learning approach, enables students to tackle sophisticated, real-world problems through repeated cycles of testing and refinement.

The “Will It Float?” project was developed to bridge the gap between theoretical concepts and practical applications in first-year engineering courses [1]. This challenge encourages students to engage with fundamental engineering principles, such as buoyancy and fluid dynamics, in a highly interactive and collaborative manner. By introducing CAD modeling and 3D printing, the project also provides students with exposure to modern design and manufacturing techniques, which are essential in contemporary engineering practice.

This challenge was structured to promote creativity within the constraints of size and fabrication time, mimicking real-world engineering scenarios where resources are limited. Students were guided to think critically about design trade-offs, optimize their solutions through iterative testing, and reflect on their experiences to deepen their understanding of the design process.

The broader aim of this initiative is to prepare students for professional engineering environments by instilling a mindset of systems thinking, adaptability and resilience. By navigating challenges such as structural instability, shifting weights, and wave dynamics, students develop problem-solving skills that extend beyond the classroom. This approach aligns with the growing emphasis on experiential learning in engineering education, which seeks to combine theoretical knowledge with practical, hands-on experimentation.

By integrating iterative design [2] and reflective learning [3], the “Will It Float?” design challenge serves as a platform for students to explore engineering concepts in depth while building essential skills for their future careers. This study aims to contribute to the ongoing discussion on improving engineering education through innovative teaching methods and structured design challenges.

2. Objectives

The “Will It Float?” project was designed to:

1. Reinforce theoretical understanding of buoyancy and fluid dynamics by connecting classroom concepts to a hands-on design challenge.

2. Develop students’ proficiency in computer-aided design (CAD) software, including tools such as Inventor, SolidWorks, and TinkerCAD, which were introduced as part of the course curriculum.

3. Cultivate iterative problem-solving and adaptability by requiring students to refine their designs through progressive testing under increasingly complex conditions.

These objectives were implemented in the context of a first-year, introduction to mechanical engineering course that introduces students to foundational engineering concepts and practical applications. The boat design challenge served as the semester’s capstone project, providing a practical framework for applying theories of buoyancy and fluid dynamics.

Design Challenge Parameters

The design brief provided students with specific constraints to guide their creativity and problem-solving efforts. Key parameters included:

- *Boat Dimensions:* Maximum length of 4.5 inches, width of 3 inches, and height of 3.5 inches to ensure compatibility with department 3D printers.
- *Material Constraints:* Boats were fabricated using PLA plastic, requiring designs to account for 3D printing limitations, such as moderate angles (<50°) and avoidance of overhangs requiring support material.
- *Collaborative Work:* Students worked in teams, emphasizing the importance of communication and shared responsibility.
- Iterative Testing: Initial tests were conducted in still water, followed by tests involving wave simulations to replicate dynamic environmental conditions.

Activity Goals

The project aimed to balance technical skill development with creativity and teamwork. Through iterative testing, students were encouraged to refine their designs to optimize buoyancy, stability, and structural integrity. Teams documented their progress through design logs and technical presentations, culminating in a final competition to evaluate the buoyancy and aesthetic quality of their boats.

This structured approach ensured students not only developed a deeper understanding of the principles of buoyancy but also gained hands-on experience in iterative design and teamwork, key skills for their future engineering careers.

3. Practical Implementation

Initial Activities

The project began with a tin foil boat activity, introducing basic principles of buoyancy and fluid dynamics. Through tinkering, they were encouraged to experiment with the phenomenon and learn as much as they could [4]. Students engaged in a homework assignment to deepen their understanding of buoyancy and density through engineering analysis.

Design Challenge

Students utilized Autodesk Inventor and other CAD tools introduced in the ME-110 course to create models for their boats. These models adhered to strict size constraints, 4.5 inches in length, 3 inches in width, and 3.5 inches in height, to ensure compatibility with the department's 3D printers. Students were also guided on how to design effectively for additive manufacturing, considering factors such as print angles and material limitations.

Testing and Iteration

The iterative testing process spanned several cycles, each introducing new challenges:

- *First Cycle:* Boats were tested in still water using ball bearings of 0.25", 0.5", and 0.75" diameters as ballast. Students quickly discovered that the weights were not static and rolled within the boats, introducing a systems engineering aspect to the challenge. This unexpected dynamic required teams to reconsider their designs to improve weight containment and stability.
- *Secondary Cycle:* A second round of testing introduced wave-generating underwater fans in a fish tank to simulate choppy water conditions. This added complexity forced students to adapt their designs further, accounting for the external environmental factors affecting their boats' performances.

Demonstration Day

The project culminated in a final competition where teams tested their boats under these dynamic conditions. Some groups, benefiting from early iterations and insights, achieved significant improvements in their designs [5]. Students documented these refinements and presented their findings in technical presentations, showcasing their understanding of buoyancy, stability, and the iterative design process.

This hands-on approach reinforced key engineering concepts while exposing students to real-world problem-solving scenarios, helping them build foundational skills in design, analysis, and teamwork.

4. Assessment Methods

Quantitative Measures

Boat performance was evaluated using the buoyant efficiency metric (weight held vs. boat weight). Fourteen boat projects were categorized into patterns and strategies, highlighting common features such as box-shaped hulls, weight slots, and pontoons. These features emerged as students iterated on their designs to address dynamic testing challenges.

Qualitative Analysis

Semi-structured interviews captured students' decision-making processes and responses to design challenges. These interviews revealed a shift from creative initial concepts to more functional and efficient designs as students encountered real-world constraints, such as rolling weights and wave effects.

Documentation Review

Students documented their design processes, iterations, and testing outcomes. These reports, along with photos and diagrams of initial and final designs, were analyzed to trace how features like pontoons and internal compartments evolved to improve performance.

Oral and Written Presentations

Assessment also included an oral presentation and a written report. Teams were required to deliver a 6-minute presentation summarizing their design process, testing outcomes, and lessons learned. These presentations were complemented by a detailed written report, which included:

- A description of the design process and preliminary concepts.
- Engineering calculations used to inform the design.
- Images and descriptions of the final boat design.
- Reflections on performance in the competition and lessons learned.
- An evaluation of team collaboration and individual contributions.

The combination of oral and written presentations ensured that students developed strong communication skills alongside technical expertise, reinforcing the importance of effectively articulating engineering ideas.

5. Results

The categorization of the boats was done for both the students' initial prototypes as well as their final boats. This was done to observe trends between groups and to observe design changes. Example boats are illustrated below in Figure 1.

Figure 1. Examples of 3D printed “boats”

These boat designs are seen below in Tables 1 and 2. To see which designs proved to be more efficient, a chart was created that ranked the buoyant score (weight held divided by the weight of the boat) for each boat. This can be seen in Table 3.

Table 1. Initial Prototype Boat Characteristics

Design	*box*	*angled*	*fishing*	*weight*	*cargo*	*overflow*	*pontoon*	*small*	*curvy*	*thin*	*lip on*	*hollow*
1									■			
2	■											
3		■						■				
4							■					
5	■						■					
6	■											
7	■							■				
8		■										
9	■	■										
10	■											
11	■					■						
12					■							
13	■	■		■								
14		■	■									

Table 2. Final Prototype Boat Characteristics

Design	*box*	*angled*	*fishing*	*weight*	*cargo*	*overflow*	*pontoon*	*small*	*curvy*	*thin*	*lip on*	*hollow*
1	■	■										
2	■									■		
3		■								■		
4	■						■					
5	■						■			■		
6	■			■			■					
7	■			■								
8		■		■								
9	■	■		■								
10	■			■						■		
11	■			■							■	
12	■	■		■							■	■
13	■	■		■						■		
14	■						■				■	

Table 3. Boat Performance

Design	*weight held*	*buoyancy score*
1	300g	2.5
2	723g	6.7
3	403g	5.6
4	48g	0.6
5	8g	0.1
6	871g	6.4
7	545g	4.3
8	257g	5.1
9	168g	3.5
10	-	-
11	724g	12.5
12	-	-
13	544g	6.8
14	-	-

6. Findings

The iterative design process underscored the importance of adaptability and problem-solving. Initial creative concepts evolved significantly as students encountered real-world constraints. For instance, the inclusion of box-shaped hulls and internal compartments addressed the movement of rolling weights, while the addition of pontoons improved stability under dynamic testing conditions.

These findings highlight how students' designs progressed from creative prototypes to more efficient and functional solutions. The categorization of 14 projects provided insights into design patterns and strategies, with recurring features like thin lips on hollow designs and weight slots emerging as effective solutions.

Furthermore, students' ability to incorporate feedback from testing cycles demonstrated their growth in systems thinking, as they accounted for external factors such as water movement and ballast dynamics. This iterative learning approach reinforced the value of experiential projects in developing engineering competencies.

The results showcase how structured design challenges foster creativity and technical skill development while exposing students to real-world engineering scenarios. These experiences highlight the potential of iterative design activities to prepare students for the complexities of professional practice.

The key findings are:

1. Students initially focused on maximizing boat volume but later optimized weight distribution and structural integrity. Some were stuck on their first ideas, however [6].
2. Common features in final designs included box-shaped hulls, weight slots, and pontoons, indicating convergence toward effective solutions.
3. Patterns emerged in how students adapted their designs to deal with unexpected dynamics, such as rolling weights and wave-induced instability, reflecting a transition from creative initial approaches to refined, performance-oriented solutions.

6. Practical Recommendations

Educators can integrate similar design challenges by implementing the following:

1. *Balancing Theory and Practice:* Design challenges should connect theoretical principles to practical applications, ensuring students see the relevance of concepts like buoyancy and structural integrity. Start with a theoretical foundation, then transition to hands-on activities.
2. *Encouraging Iterative Learning:* Allow multiple cycles of design, testing, and refinement to give students the opportunity to respond to real-world constraints and improve their designs. Emphasize that failure is an expected and valuable part of the learning process.

3. *Leveraging 3D Printing:* Utilize 3D printing as a tool to support iterative learning. Rapid prototyping capabilities enable students to test, evaluate, and modify designs efficiently, helping them understand the interplay between design, material properties, and manufacturing constraints. By physically interacting with their prototypes, students gain deeper insights into the consequences of design decisions and develop an appreciation for manufacturing considerations.
4. *Supporting Design Process Navigation:* Help students understand the non-linear nature of the design process. Highlight how initial creative exploration can evolve into more structured problem-solving as constraints are discovered. Encourage flexibility and iterative thinking as students navigate unexpected challenges.
5. *Incorporating Real-World Complexity:* Introduce dynamic variables such as rolling weights, wave simulations, or environmental factors to push students to think beyond static scenarios. These challenges foster systems thinking and help students anticipate external influences on their designs.
6. *Fostering Team Collaboration:* Encourage teamwork by assigning roles within student groups, such as design lead, testing coordinator, and documentation specialist. Structured roles ensure balanced participation and highlight the importance of effective communication.
7. *Providing Detailed Feedback*: Offer constructive and timely feedback after each iteration. Guide students to focus on specific aspects of their designs, such as stability or material efficiency, while allowing them to independently explore solutions.
8. *Assessing Both Process and Product:* Evaluate not only the final outcome but also the iterative process, including how students approach challenges, adapt their designs, and apply theoretical knowledge. Include oral presentations and written documentation to assess communication skills alongside technical proficiency.
9. *Integrating Reflection:* Require students to reflect on their design decisions, challenges faced, and lessons learned. Reflection helps students internalize key concepts and develop a growth mindset.

These recommendations highlight the potential for design challenges to serve as transformative learning experiences. By incorporating iterative processes, real-world complexity, and collaborative opportunities, educators can prepare students for the multifaceted demands of engineering practice. Through the thoughtful integration of 3D printing, students not only visualize but also physically engage with their ideas, making the design process both tangible and impactful.

7. Conclusions and Future Work

The “Will It Float?” project demonstrates the educational value of integrating hands-on design challenges into first-year engineering curricula. Through iterative cycles of design, testing, and refinement, students developed a deeper understanding of buoyancy principles and the engineering design process. The project fostered critical thinking, teamwork, and adaptability, equipping students with essential skills for professional practice. By leveraging 3D printing, students gained practical experience in prototyping and manufacturing, reinforcing their ability to translate theoretical knowledge into tangible solutions.

The study also highlights the importance of embedding real-world complexities, such as dynamic testing conditions and external constraints, into educational activities. These challenges simulate professional scenarios, encouraging students to think systemically and adapt creatively. Overall, the project underscores the potential of iterative, experiential learning to prepare students for the multifaceted demands of engineering careers.

Building on the findings from this project, future work can explore the following areas:

1. *Expanding Design Challenges:* Incorporate additional variables, such as material alternatives or environmental sustainability considerations, to broaden the scope of learning outcomes.
2. *Scaling Iterative Processes:* Investigate how iterative design methodologies can be applied in larger group settings or across interdisciplinary teams.
3. *Integrating Advanced Manufacturing Tools:* Introduce technologies like CNC machining or laser cutting alongside 3D printing to enhance students' understanding of diverse manufacturing processes.
4. *Assessing Long-Term Impact:* Conduct longitudinal studies to evaluate how participation in iterative design projects influences students’ performance in advanced coursework and professional settings.
5. *Enhancing Feedback Mechanisms:* Develop automated or peer-based feedback systems to provide real-time insights during the design process.
6. *Exploring Remote Learning Adaptations:* Adapt the project for hybrid or fully remote learning environments, utilizing virtual CAD tools and remote fabrication facilities.

By pursuing these directions, educators can continue to refine and expand the impact of experiential learning activities, ensuring that engineering students are well-equipped for the challenges of an ever-evolving field.

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