Engineering Educators Bringing the World Together
2025 ASEE Annual Conference & Exposition
Palais des congrès de Montréal, Montréal, QC • June 22–25, 2025
Paper ID #46389

Coming Unglued: Restricting Adhesives in Undergraduate Mechanical Engineering Design-and-Build Projects (Marble Machine Edition)

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Coming Unglued: Restricting Adhesives in Undergraduate Mechanical Engineering Design-and-Build Projects (Marble Machine Edition)

Abstract

College-level sophomore and junior mechanical design-and-build laboratory courses are critical in helping engineering students develop practical skills for mechanical systems. However, many students struggle with basic mechanical components and fasteners, often failing to identify standard parts on sight. This lack of foundational knowledge, in conjunction with suboptimal project management habits, often results in over-reliance on adhesives. This is particularly problematic in situations where adhesives are used inappropriately—such as gluing gears to round shafts instead of using mechanical solutions like D-shafts, keys, or set screws. Even in cases where adhesives are correctly applied, overuse often results in poor tolerances, weak joints, misaligned parts, and overall structural instability.

To address this issue, this paper presents a customizable design-and-build Marble Machine project, where a critical rule prohibits the use of general adhesives as a joining method. Adaptable for undergraduate students ranging from freshmen to seniors, this project emphasizes proper mechanical assembly techniques. The absence of adhesives encourages exploring catalogs of mechanical components for efficient and economical solutions, reinforcing the importance of specification compliance and smart tolerancing, minimizing excessive vibration and ensuring stability.

The Marble Machine project's complexity can be tailored to the varied skill levels, deepening the understanding of mechanical systems and avoiding temptations of quick fixes such as glue—especially when working with additively manufactured parts under tight deadlines. Students subjected to the no-adhesive rule seem to produce higher-quality projects, with better mechanical integrity and functional design.

The Marble Machine project and the restriction on adhesive use is measured both qualitatively and quantitatively. Devices are assessed for mechanical performance and knowledge of standard mechanical components and fasteners. Additionally, a survey is conducted to gauge students' perspectives on the learning experience.

This project contributes to all seven ABET student outcomes, depending on how the assignment is customized, making it a highly effective tool for both skill development and practical education in mechanical design.

1. Introduction

Mechanical design-and-build courses at the sophomore and junior levels prepare engineering students for practical applications in the field. These courses provide opportunities for hands-on learning, where students translate theoretical knowledge into functional mechanical systems. By engaging in design-and-build projects, students develop critical skills such as problem-solving, teamwork, and project management. However, in the face of their first function-driven design project, it is easy for students to overlook the importance of selecting standard mechanical components and/or assembly techniques.

One significant issue is the over-reliance on adhesives as a joining method in mechanical assemblies. Students frequently use adhesives inappropriately, such as gluing gears to round shafts rather than employing mechanical solutions like D-shafts, keys, pins, or set screws. This approach often leads to weak joints, poor tolerances, and structural instability. Even when adhesives are applied correctly, excessive reliance on them may indicate a lack of familiarity with mechanical fastening options, undermining students' readiness for real-world engineering challenges.

There is a pressing need for project-based learning methods that emphasize the use of standard mechanical components and proper assembly techniques. To address this issue, the paper present a Marble Machine Project that prohibits the use of adhesives, providing a hands-on platform to strengthen student familiarity and comfort with fasteners. By requiring students to explore catalogs of mechanical components and design adhesive-free solutions, the project encourages critical thinking about the mechanical integrity and criticality of joints in the context of a functional design. The Marble Machine project outlined herein is a versatile tool aimed at equipping students with the skills needed for success in mechanical engineering.

This paper presents the design and implementation of the Marble Machine project and the key constraint of disallowing adhesives. The gap in student knowledge and the impact of the project parameters upon student learning is assessed through qualitative and quantitative assessments. Finally, this paper highlights the project’s alignment with ABET student outcomes, offering a replicable activity that enhances undergraduate mechanical engineering education.

2. Background and pedagogy

2.1 Importance of design-and-build projects

Design-and-build projects have become a staple in engineering education, fostering critical thinking and practical skills [1]-[3]. These projects emphasize real-world problem solving and provide a platform for applying theoretical knowledge. Examples include developing models for manufacturing or prototypes for operational testing, which serve as essential training grounds for the reality of engineering and assembly practices. Students often perceive they learn significant skills from the hands-on experience of design-and-build projects, and the benefits of such educational activities have become widely accepted. [4-10]

However, it is common for students to first encounter these experiences in the Senior Design/ Capstone Design projects, and may have little preliminary design instruction prior. Providing support and opportunities to grow student manufacturing skills is critical at earlier levels, as this skill set allows them to achieve better results and more nuanced, experience-based lessons during design-and-build projects [11].

Junior level design-and-build projects are especially important, as they can serve as a stepping stone between early-curriculum independent activities and outward-facing, industry-based Senior Design/Capstone projects [10,12]. To accomplish the transition, the transitional design-and-build project should be team-based, require creative problem-solving within a limited budget and time-frame, and produce a physical product whose performance is assessed by multiple (oft competing) requirements [13-15].

Due to shifts in the k-12 curriculum over time, fewer students enter college with the more traditional fabrication skills learned in "shop" classes [10]. This same trend can be observed within the context of the technological advancement of vehicles, where fewer students grow up working on their car. Instead, many modern vehicles require specialized tools to even access car components, and often require the car be serviced at specific dealerships. There are less opportunities for young people to be exposed to industrial components, such as shafts, keys, spring shocks, etc. The design-and-build projects at the collegiate level may be the first true exposure some engineering students have to fastener and mechanical components.

2.2 Rationale for restricting adhesives in design-and-build projects

Mechanical fasteners are a critical aspect across industries and provide joints that are secure, repeatable, and often reversible. Despite their importance, fasteners are frequently under-appreciated and sometimes overlooked. Philip Absalom [16] described it best:

> *"Fasteners, it seems, are like discreet waiters in a decent restaurant: you don't notice them until they're missing."*

While adhesives can be utilized to great effect and have several benefits, they can result in structural issues when used improperly. The required precision for correct and consistent application is frequently underestimated. There are many attributes to recommend the use of adhesives over mechanical fasteners, such as weight considerations and the freedom of placement, but there are just as many drawbacks which mechanical fasteners answer. Table 1 provides a brief comparison that is broadly applicable, but, like all things in the engineering field, there are special cases for all items listed that will not be addressed.

Like any other tool, there is a proper time and place for appropriate application of both adhesives and fasteners. However, students under the pressure of a deadline will often be tempted to disregard engineering logic and instead opt for a quick fix up front that will cause significant challenges later and sacrifice the overall product quality.

Restricting adhesives compels students to explore proper fastening methods, tolerances, part compatibility, and assembly best practices. This approach also mitigates long-term maintenance challenges, as mechanically fastened assemblies are generally easier to service. This is particularly salient for undergraduate projects where students less experienced in project management may find themselves pressed for time close to the deadline. By restricting the use of adhesives, the Marble Machine project strengthens the students' mechanical competencies while aligning with ABET student outcomes [17].

Table 1: Broad comparison of general adhesives and mechanical fasteners.

	General Adhesives	**Mechanical Fasteners**	
Reliability		✓	
Requires Cure Time	✓		*Curing requires additional assembly time.*
Ease of Reversibility		✓	*Some adhesives are reversible, but require additional chemicals or heat.*
Ease of Repeatability		✓	
Lightweight	✓		*Up to 15% heavier than adhesive; cumulative weight becomes an issue [18].*
Fire Resistant	✓		
Corrosion Resistant	✓	~	
Holes Through Parts		✓	*Fasteners may need additional support (washers, fixing plates, etc)*
Dampen Vibrations	~		

✓ *Typically possesses attribute* ~ *Possess attribute under certain conditions.*

2.3 Quantitative assessment of the gap in student knowledge

To assess the gap in the students' knowledge of mechanical fasteners/components, a component identification quiz was developed and implemented early in the semester before the design phase was complete. The quiz presented several pictures of various fasteners, components, and classic assemblies, and students were challenged to identify as many as possible. If the specific name was not known, there was space where the students could describe the part's function. If a student did not recognize the part at all, the answer was left blank. The images were presented without scale to test how many were recognizable parts in and of themselves with limited context clues. The assessment was repeated over 3 semesters in 2024, with an overall student population of N=125. A summary of results is presented in Figure 1.

Only 6 components were readily identified by 50% or more of the student population: spur gears, wheel and worm gears, ball bearings, hex nuts, wing nuts, and a standard washer. Other than that, a number of other common components were recognized, though the name was unknown. A prime example of this is the variety of gears presented on the quiz. Six different gear types

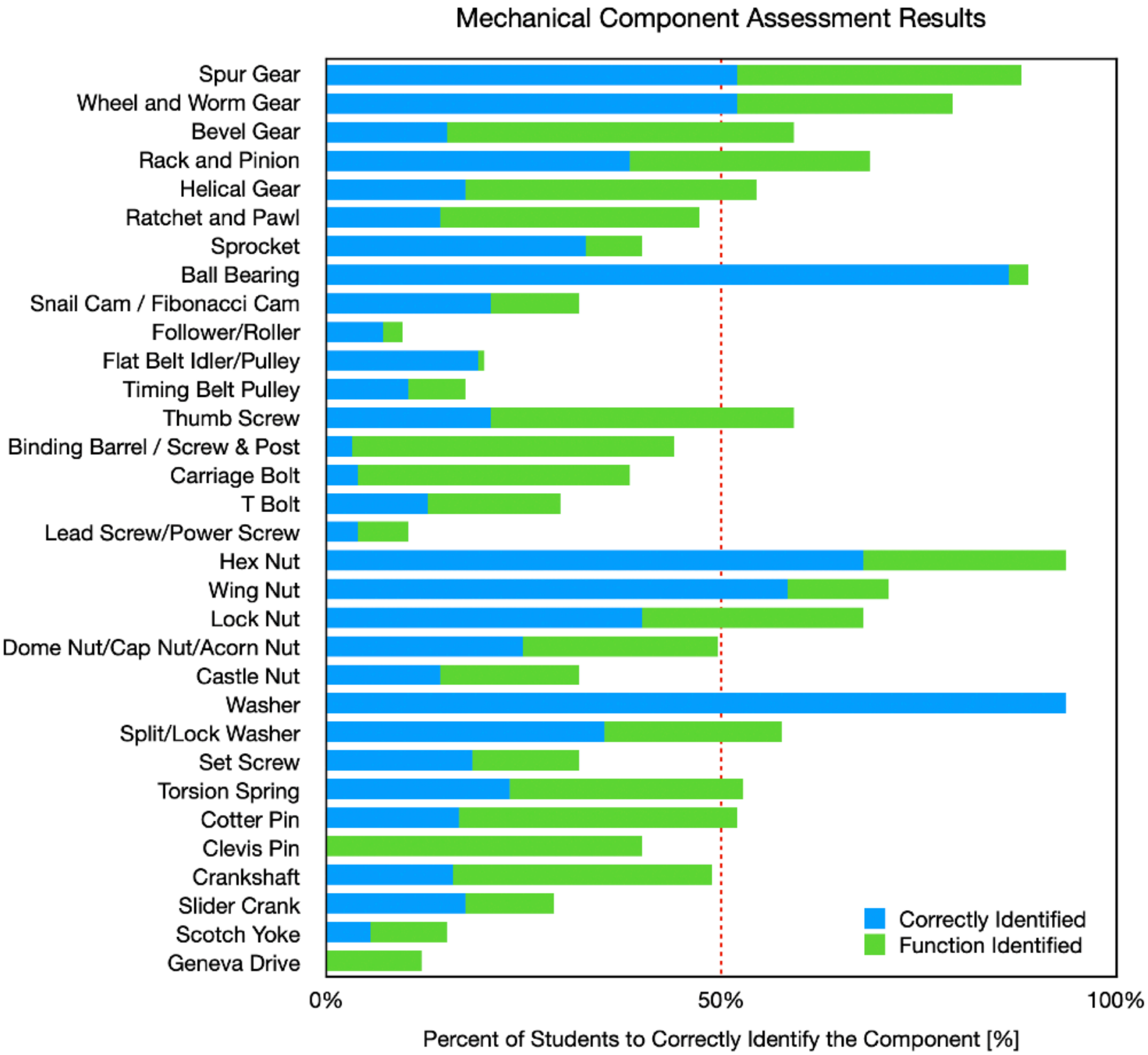

Figure 1: Results for student assessment of mechanical components prior to completing the marble machine challenge.

were shown, and at least half of the class could recognize them as belonging in that category. However, few students could identify the name, or even describe how the gear would be utilized. The trend becomes more interesting when considering common components such as pulleys and cams, where only a quarter of the class or less could recognize them. Another example is the variety of bolts and screws presented, where, with the exception of the thumb screw, less than half the students could recognize the function, and even less could identify them. It appears that the students are familiar with the general concept of gears, pulleys, bolts and nuts, etc., but the nuance of the variants within the broad categories is unknown.

This is the true gap that is concerning at the Junior undergraduate level, and which should be filled prior to Senior Design/Capstone projects. Without an appreciation for the purpose of fastener subtypes, the students cannot make decisions after meaningful consideration of needs and application. Permitting glue and other adhesives in design-and-build projects at this level prevents students from researching better joining methods and fasteners. This is why restricting adhesives full-stop is a beneficial project constraint—it motivates student to explore the hardware libraries for better, smarter solutions as opposed to quick shortcuts. Furthermore, the students must put forethought and planning into these decisions so the specific hardware can be ordered and shipped in time to be utilized in the project build. Permitting adhesives leads to crunch-time shortcuts, and the criticality of a projected timeline is lost.

3. The marble machine project

3.1 Project overview

The Marble Machine project was successfully implemented for three semesters (Fall 2023 - Summer 2024) at the Junior level mechanical engineering curriculum. The project parameters were designed with the following general goals in mind:

- The project should be reasonably complex and manufacturing quality-sensitive, but in a compact size suitable for most college manufacturing facilities and budgetary concerns.
- The final solution should result in a physical device that is primary mechanical in nature.
- The project should impart critical lessons regarding the importance of tolerancing, prototyping, and conducting a thorough failure modes and effects analysis (FMEA).
- Students should gain a realistic understanding of timelines, team dynamics, and project management challenges.
- The final product should be worthy of the students' resume/portfolios, along with newly acquired skills, so as to assist with internship/job interviews.
- Introduce a clear, all-encompassing constraint preventing students from using adhesives to prevent students from leaning on poor practices that are very tempting in the "crunch time" leading up to the deadline. Ultimately, the students appear to produce superior products when working under this constraint.
- The final grade assessment should be comprised of both qualitative and quantitative targets.
- The project performance requirements should be quantifiable, and the achievement thereof should embody engineering calculations already taught in previous classes.

The Marble Machine project was inspired by the regimented timing of an assembly line when moving projects through a system. Students were challenged to design and fabricate a machine that would continuously cycle 12 chrome steel bearings ball (0.5 inch diameter) at a rate of 30 balls/minute for 3 consecutive minutes, while evenly distributing every other ball bearing to 2 separate delivery points.

Key project constraints:

- **Size Constraint**: The full device must fit within a 12” x 12” x 12” challenge zone.
- **Cost Constraint**: The Bill of Materials must be less than $100.
- **Power Constraint**: The system must be driven solely by a 25 rpm 3 Volt motor, powered by 2 AA batteries with a clear on/off toggle switch. The electrical components were provided by the instructor to maintain consistency between teams. No other electronics are permitted.
- **No adhesives** of any kind are permitted—mechanical joining/fastening methods only.

Key performance requirements:

- **Cycle Rate**: The device must cycle the bearing balls at a *constant* rate of 30 balls/minute.
- **Operation Time**: The device must run continuously for 3 minutes without interference.
- **Delivery Paths**: There must be exactly 2 separate and distinct paths between which the bearing balls must be evenly sorted.
- **Sorting Function**: *Every other* bearing ball must be directed down different paths.
- **Hopper**: While a single collection hopper is *not* strictly required, all 12 bearing balls must eventually re-converge onto the same path at the location of release. The location of release is synonymous with the location where the bearing balls are cycled to the state of highest potential energy, and where the cycle rate is measured.
- **Complex Feature**: Separate and distinct from the cycle and sort function(s), there must be a complex feature along 1 or both of the travel paths that obviously changes the direction and velocity of the bearing ball. No two teams may utilize the same complex feature.

Note that the list of parameters are representative but not all-encompassing. For complete documentation of the project rules, requirements, and grading rubric, see Appendix A.

3.2 Advice for implementation

To ensure successful implementation of the Marble Machine project and to maximize the educational benefits for students, the following recommendations are provided based on prior experiences and observations.

3.2.1 Measuring the system’s cycle rate

Allow students to select their preferred method for measuring the system’s operational rate. Two common examples of measurement methods are (a) the N=N method (where the rate is determined by timing how long it takes for 10 balls to pass by a checkpoint) and (b) the N-1 method (where the rate is determined by timing how long it takes 10 ball to pass a checkpoint in addition to the final time increment). This decision requires critical thinking about the design and its implications regarding motor speed, and it reinforces how system measurements impact control systems, quality assurance, and mechanical design integration.

By assigning this responsibility, students are compelled to not only research industrial practices, but to reason out how their theoretical calculations will play out during the practical testing phase.

3.2.2 Adhesive restrictions

To simplify enforcement and maintain focus on the educational objectives, it is recommended to impose an all-encompassing adhesive restriction. While certain adhesives (e.g., threadlockers for nuts and bolts) are commonplace in practical engineering, introducing exceptions often shifts student attention toward exploiting loopholes rather than constructive problem-solving. The top two student queries regarding this project constraint are as follows:

1. Does "Plastic Welding" count as an adhesive?

   Plastic welding is a popular practice in the 3D printing world, where a soldering iron is utilized to "weld" two plastic parts together along the seams. While it not a traditional adhesive, it is recommended instructors prohibit "plastic welding as a joining method because it deviates from the intent to prioritize mechanical fastening techniques.

2. Can we use adhesive to stiffen parts or make epoxy composites?

   While a grey area, it has been proven successful to allow the use of these techniques on a case-by-case basis. It is important to emphasize that these techniques are being used as fabrication methods rather than joining methods. This nuance aligns with the educational focus on proper assembly techniques.

3.2.3 Power source considerations

Students often underestimate the influence of power source variability on system performance. The labeled battery life/supply is often different from the actual performance/delivery. As batteries deplete, operational consistency diminishes. It is important to emphasize this to the students, as many will overlook or even be unaware of the need to account for power variations in mechanical and control system designs.

3.2.4 Recommended material amount

Mandate the use of at least 12 bearing balls in the system (when utilizing 1/2" chrome steel bearing balls). Marble machines driven by a 3V 25rpm motor generally perform well with 10-11 bearing balls, but introducing a 12th ball creates opportunities for meaningful analysis and iterative testing. This requirement drives students to optimize the design of lift mechanisms, such as augers, wheels, or conveyor belts, to account for the additional weight. Twelve bearing balls appears to be the key boundary under the project constraints.

For example, an auger-based lift mechanism requires optimization of pitch, angle, and length to accommodate the extra bearing balls without compromising efficiency. Students will commonly create vertical, tall augers that hold all 12 balls on the first iteration out of a desire to maximize height of the overall machine. However, it is difficult for the auger to hold that much cumulative weight and frictional resistance and maintain a constant rate of revolution. This design challenge reinforces critical engineering principles, the importance of engineering analysis driving the sizing to meet performance, and the importance of prototype testing.

3.3 Opportunities for customization

The Marble Machine project offers a flexible framework that can be tailored to different educational objectives and student skill levels. Some opportunities to expand on the project are as follows:

1. To keep the project reasonably unique semester to semester, the target cycle rate can be increased or decreased. As long as the target rate is not the same as the motor output, there will be opportunities for students to learn about gear and pulley ratios to, for example, “gear up” or “gear down”. This also prevents previous semester analysis from being copied outright.

2. Requiring specific fabrication methods, or simply requiring some threshold amount of fabrication techniques is a good way to expand the project or keep it unique between semesters. For instance, requiring machining, welding, or additive manufacturing methods broadens students’ design-for-fabrication knowledge and encourages exploration of different manufacturing processes.

3. Requiring a greater or lesser numbers of complex features on each marble machine is a good opportunity to adjust the overall complexity for different sized or experienced teams.

4. Increasing or decreasing the number of bearing balls required to be utilized by the system can make the project more or less challenging. More bearing balls will require more detailed analysis on part sizing and timing to prevent a jam or build-up in the system. Fewer bearing balls will make the performance more achievable with less analysis, which is a good idea for a freshman variant of this marble machine challenge.

5. Removing the electronics from the challenge and switching to manual operation would also be a smart simplification for a freshman or sophomore level challenge. For example, the motor can be replaced with a hand-crank mechanism. Eliminating electrical components simplifies the project, reduces the cost and resource requirements, and focuses student attention on mechanical design and assembly.

By leveraging these customization options, educators can tailor the Marble Machine project to align with their particular educational goals and student skill levels.

4. Assessment and results

During prior semesters where adhesives were permitted, it was common to see poor design and fabrication/assembly choices that ultimately proved detrimental to the device performance, and, in many cases, led to catastrophic failures. A handful of common examples can be seen in Figure 2, though it is by no means an exhaustive sampling.

Figure 2 (a) and (b) are a prime example of an adhesive shortcut that led to functional failure of the device. Two motors were secured onto a quarter-inch laser-cut acrylic chassis and drove two wheels that were used to launch a golfball. While the acrylic itself saw limited deflection, the glue permitted excessive lateral shift resulting in the wheels spreading apart rather than propelling the projectile. Figure 2 (c) and (d) are two examples of one of the most common shortcuts: glueing component with round holes onto round shafts without any other means of securing position or transmitting torque. Most cases inevitable end with the glue shearing under

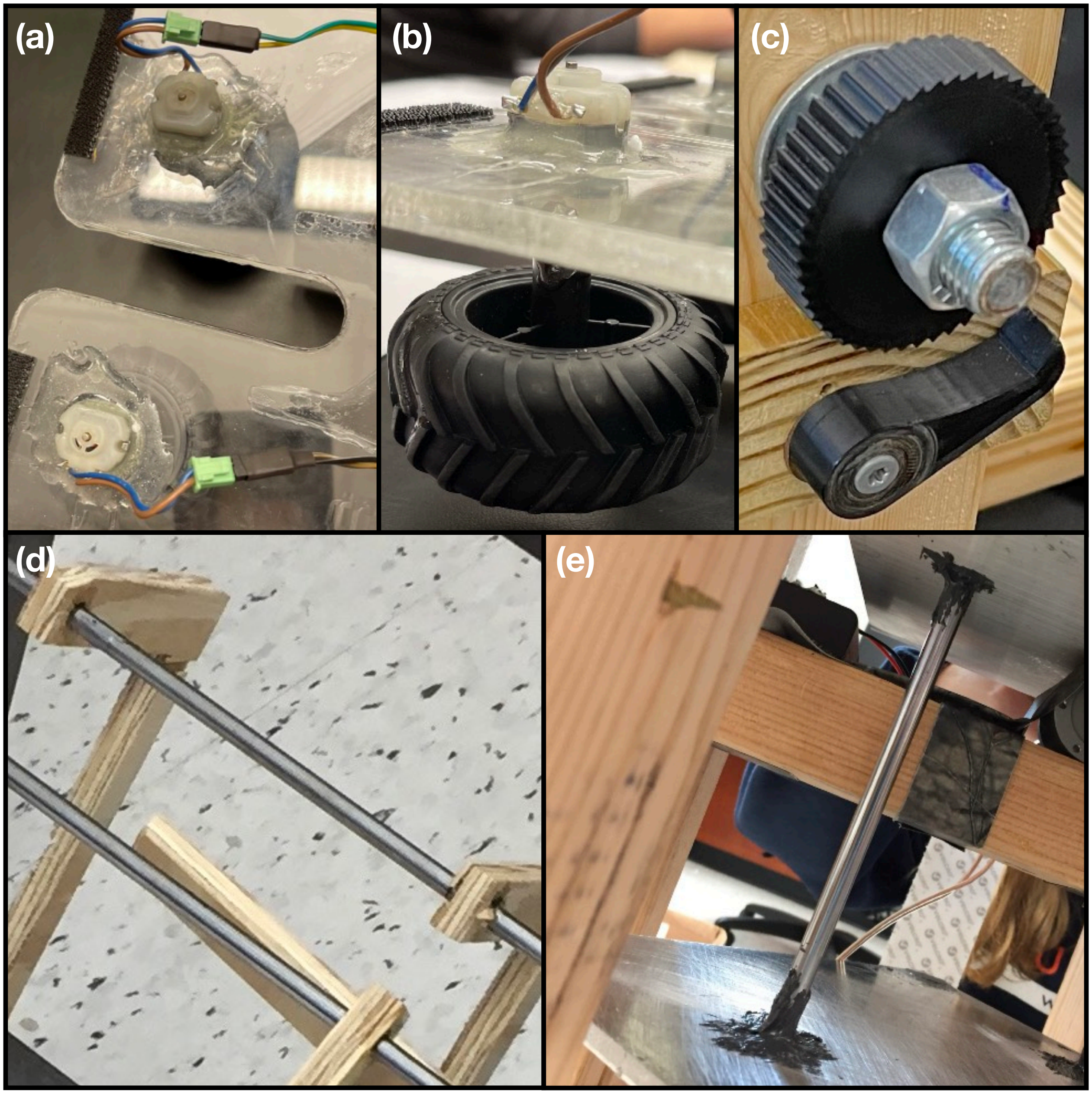

Figure 2: Examples of adhesive-aided shortcuts made on student projects.

repeated loading, leading to functional failure. The shortcut in Figure 2 (e), where support structures are glued between levels in the chassis or other, leads to significant racking in the overall structure, which typically impedes device performance. While it does not always lead to catastrophic failure, it does typically lead to such wear and tear on the device overall that it becomes inoperable if a second demonstration is needed. Overall, during a typical semester, approximately half of the teams would have low- to non-performing devices at the end of the semester, and only about 30% of teams would have competitive solutions.

Once adhesives of any sort were restricted, fewer shortcuts were seen in the student devices and design choices improved overall. Additionally, a wider variety of mechanical components and fasteners were present across the team devices. Figure 3 provides several examples of better methods employed in areas that would have been prime opportunities for an adhesive shortcut. Overall, only ~20% of teams had low- to non-performing devices, and nearly half of the solutions are competitive.

As seen in Figure 3 (a)-(c) and (d), rather than gluing motors and other components in place, proper mounting plates and brackets were utilized. Figure 3 (d), (e), and (g) demonstrate proper use of keyed shafts, screws, and d-shafts to transmit torque, which is much more effective and long-lived than adhesives that were commonly used prior to the project restriction. Figure 3 (h) shows properly embedded bearings, bolted assembly pieces, and support rings to maintain structural alignment for flexible parts.

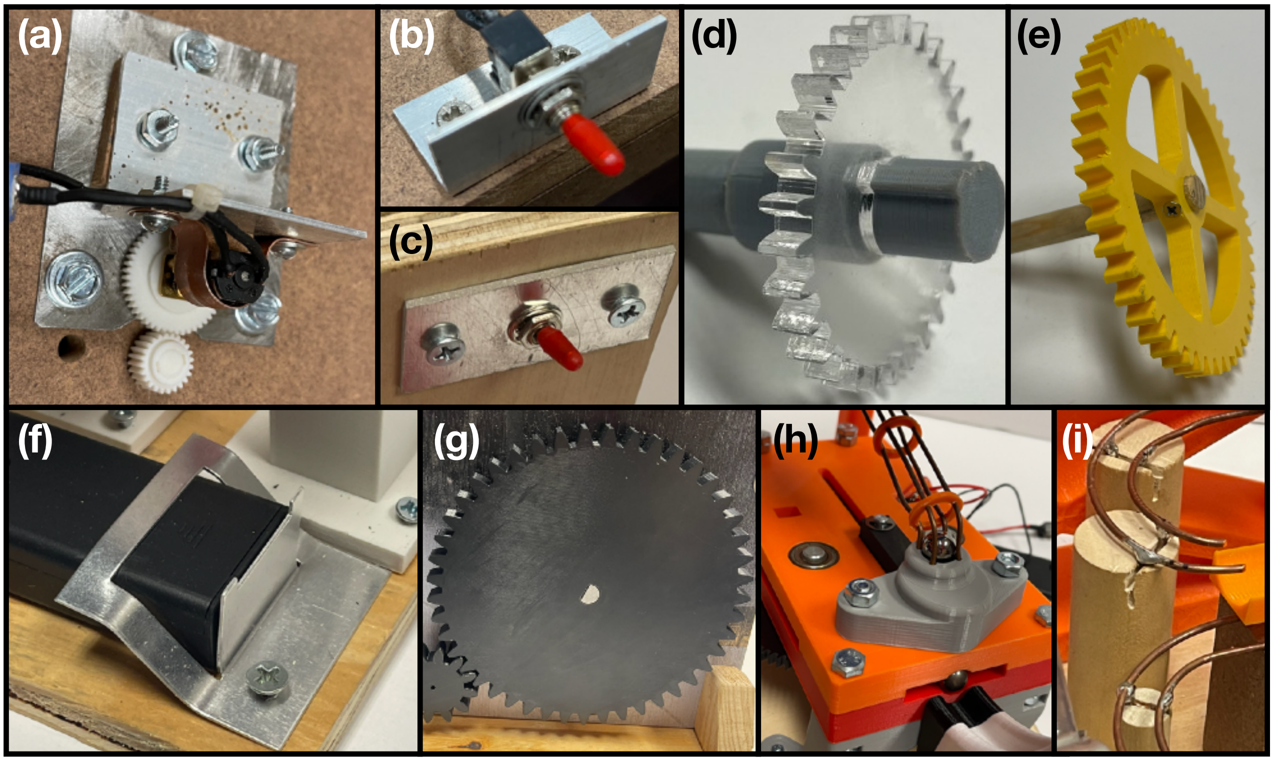

Figure 3: Examples of improved design choices in student projects after the restriction on adhesives was initiated.

Additionally, Figure 4 shows some examples of mechanical components that have not been utilized prior to the restriction on adhesive. Examples include but are not limited to linear rails and carriages, locking collars, sleeves, cotter pins, and pillow blocks to properly support bearings. Not only are the student solutions of higher quality and better performance overall, but the students also learn valuable lessons about utilizing real mechanical components. For example, the pillow block in Figure 4 is cracked, and the students learned about the critically of shaft alignment in terms beyond angle and deflection. This and similar learning experiences better prepare students for more advanced projects later in the curriculum. Sample student solutions (first semester Juniors) to the marble machine challenge can be viewed in Figure 5.

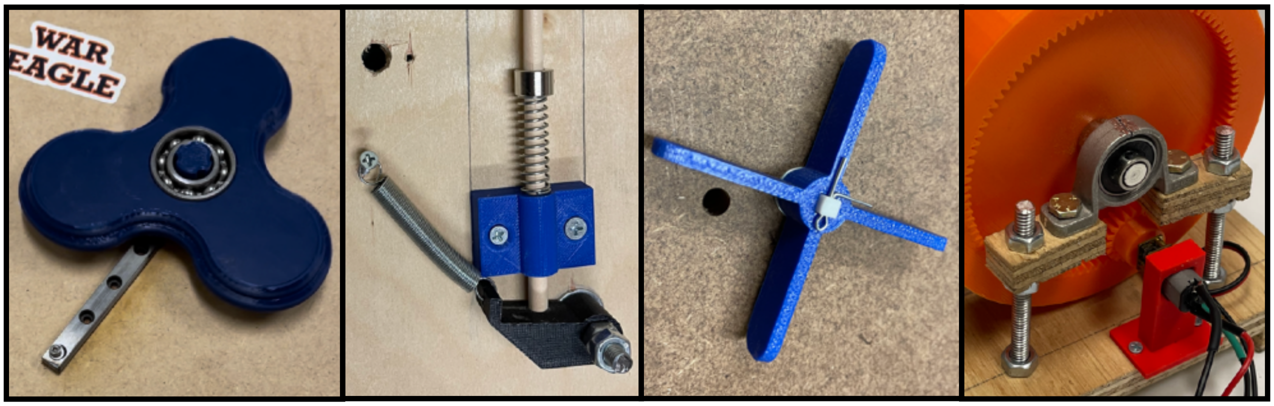

Figure 4: Samples of the increased variety of mechanical components utilized in students projects after the restriction on adhesives was initiated.

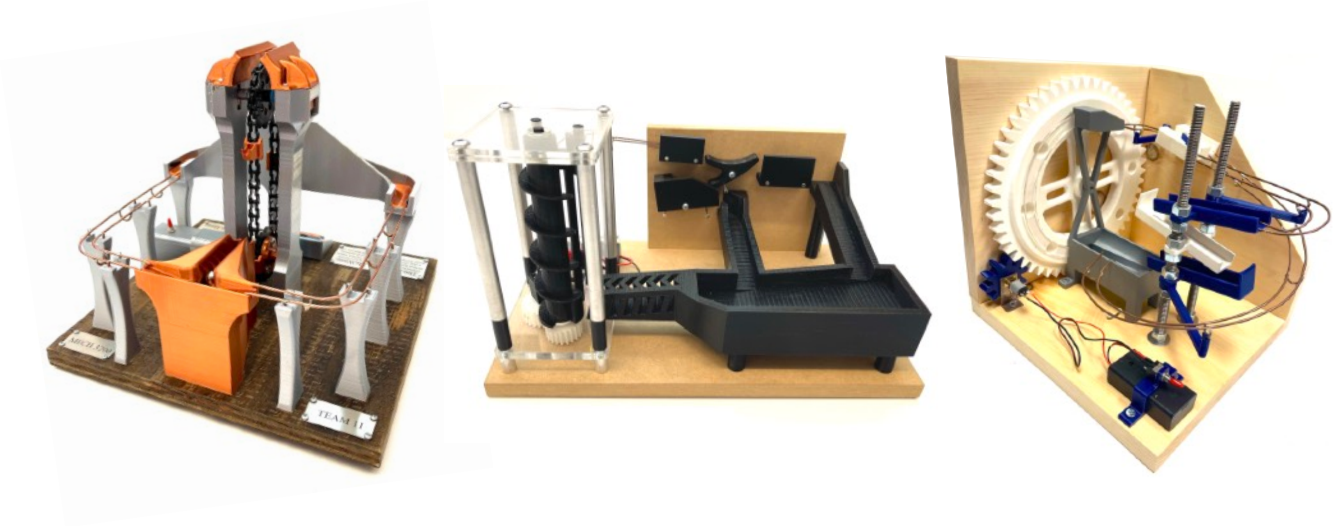

Figure 5: Sample Junior-level student solutions to the marble machine challenge.

The marble machine project and the restriction upon adhesives fills a critical gap in student knowledge. The consistent quality of student devices speaks to the success of the adhesive restriction. When polled at the end of the project, 55.0% of students reported that their design skills had improved, 44.4% of students reported that their design skills had significantly improved, and only 0.6% of students reported that their design skills had not improved. These percentages span 3 semesters with a sample size of N=160 students. Upon completion of the marble machine challenge, students appear to be better and more confident designers.

5. Conclusion

The marble machine challenge is an undergraduate design-and-build project that includes a key restriction against the use of any adhesives. This project along with the no-adhesive constraint was developed to address a gap in student knowledge regarding mechanical fasteners, joining methods, and components. An assessment determined that less than half of the students (and often less than a quarter of the class) were able to identify a wide range of parts, especially when it came to differentiating between variants in the same category (ex: different types of bolts, nuts, and gears).

By restricting the use of adhesives, students rose to the occasion and explored the catalog of fasteners and components to find good solutions. The overall quality of devices built for the challenge saw an uptick in functionality and quality, since the students had to put greater forethought and consideration into their design choices. Additionally, since no adhesives created permanent joints, troubleshooting their prototyping effort made improvements much easier to implement. Students may have been more open to design iteration when joints were impermanent, resulting in a more refined final product. Compared to previous semesters where adhesives were permitted, the overall spread of devices were much more functional and competitive.

The marble machine project aligns closely with several ABET student outcomes:

- Outcome 1: Solving complex engineering problems by applying engineering principles.
- Outcome 2: Applying engineering design to produce solutions that meet specified needs.
- Outcome 5: Functioning effectively on a team.
- Outcome 6: Developing and conducting appropriate experimentation, analyzing data, and drawing conclusions.
- Outcome 7: Acquiring and applying new knowledge using appropriate learning strategies.

The marble machine challenge has several opportunities for customization and can be suitable for any level of the undergraduate mechanical engineering curriculum.

6. Follow-up resources

The assignment prompt is available in Appendix A. Further assignment details, files, and sample solutions are available for use upon request. Please contact the lead author for resources.

7. Acknowledgements

The author would like to express gratitude to the Department of Mechanical Engineering of Auburn University for supporting the development and implementation of the Marble Machine Challenge.

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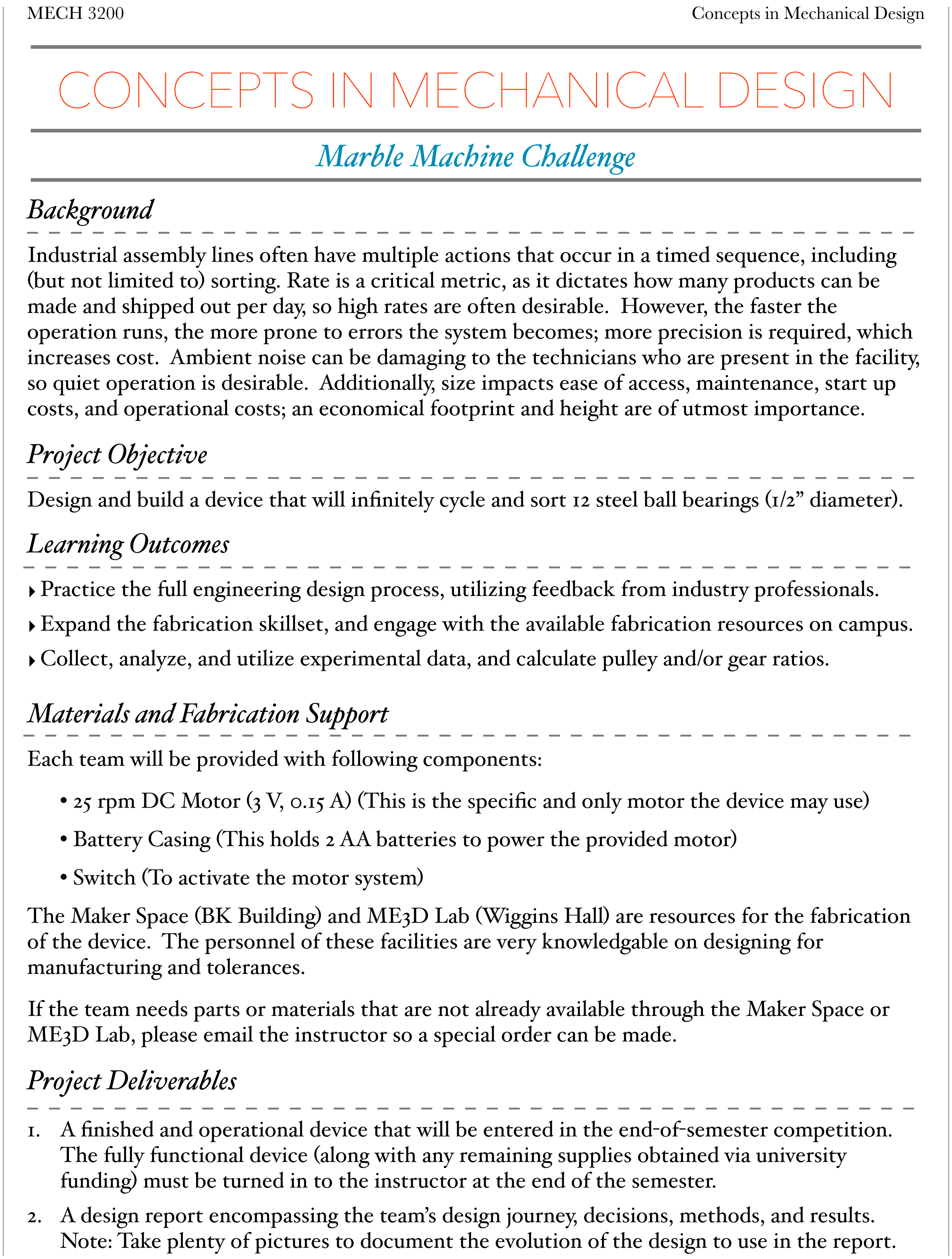
9. Appendix A



CONCEPTS IN MECHANICAL DESIGN

Marble Machine Challenge

Background

Industrial assembly lines often have multiple actions that occur in a timed sequence, including (but not limited to) sorting. Rate is a critical metric, as it dictates how many products can be made and shipped out per day, so high rates are often desirable. However, the faster the operation runs, the more prone to errors the system becomes; more precision is required, which increases cost. Ambient noise can be damaging to the technicians who are present in the facility, so quiet operation is desirable. Additionally, size impacts ease of access, maintenance, start up costs, and operational costs; an economical footprint and height are of utmost importance.

Project Objective

Design and build a device that will infinitely cycle and sort 12 steel ball bearings (1/2" diameter).

Learning Outcomes

- Practice the full engineering design process, utilizing feedback from industry professionals.
- Expand the fabrication skillset, and engage with the available fabrication resources on campus.
- Collect, analyze, and utilize experimental data, and calculate pulley and/or gear ratios.

Materials and Fabrication Support

Each team will be provided with following components:

- 25 rpm DC Motor (3 V, 0.15 A) (This is the specific and only motor the device may use)
- Battery Casing (This holds 2 AA batteries to power the provided motor)
- Switch (To activate the motor system)

The Maker Space (BK Building) and ME3D Lab (Wiggins Hall) are resources for the fabrication of the device. The personnel of these facilities are very knowledgable on designing for manufacturing and tolerances.

If the team needs parts or materials that are not already available through the Maker Space or ME3D Lab, please email the instructor so a special order can be made.

Project Deliverables

1. A finished and operational device that will be entered in the end-of-semester competition. The fully functional device (along with any remaining supplies obtained via university funding) must be turned in to the instructor at the end of the semester.
2. A design report encompassing the team's design journey, decisions, methods, and results. Note: Take plenty of pictures to document the evolution of the design to use in the report.

CHALLENGE RULES

General Description

The challenge this semester is to design and build a device that will infinitely cycle and sort 12 steel ball bearings (1/2" diameter).

General Functionality Requirements:

- Continuously cycle 12 steel ball bearings at a constant rate of 30 balls/minute for the duration of 3 minutes. This feed rate will be measured at the "launch point", which is where each steel ball bearing has peak potential energy.
- Sort and direct alternating steel ball bearings (every other one) to a different delivery location prior to being recycled. i.e. The first will be delivered to site A, the second will be delivered to site B, the third will be delivered to site A, and so on and so forth.
- There must be one other complex action/significant feature that noticeably changes the velocity of the rolling ball bearing (i.e. must be more complex than a "hill"). No team may use the same feature—each team will need to inform the instructor of their intended feature, which will be approved on a first come, first served basis.

Proving Trial Procedure and Rules

Note: Any violation of the following rules will result in a disqualification, and a 0% for the proving trial grade.

1. When the team is called to the competition station, they will have 5 minutes to place the device in the challenge zone and prepare it to run. After 5 minutes have elapsed, the team may not interact with the device except to turn it on.
2. After the team has set up the device, but before the 3 minute run begins, the max height of the device will be measured and recorded.
3. The challenge zone will be a 1 foot x 1 foot flat surface, and the device may not extend beyond the boundaries or exceed 1 foot in height at any point. The challenge zone schematic is depicted in Figure 1.
4. The device must run continuously for 3 minutes without any interference from the team. The 3 minute run will be video recorded, from which the feed rate and number of "errors" will be determined.
5. Once the 3 minute run is completed, **the device will be turned into the instructor** along with any **tools/spare parts required to operate** the device. Additionally, **any remaining parts/materials/tools that were obtained via university funding** will be turned in to the instructor at this time.
6. Scoring will occur after all teams have had a chance to compete.

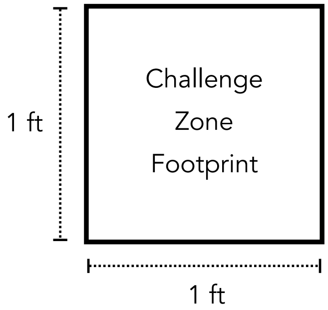


Figure 1: Challenge Zone schematic.

Device and Fabrication Rules

Note: Any violation of the following rules will result in a disqualification, and a 0% for the proving trial grade.

7. No adhesive of any kind may be utilized—mechanical solutions only. Forbidden processes or items include but are not limited to heat-setting, glue, tape, epoxy, gum, sticky-backed materials, etc. If you are unsure if something qualifies as an adhesive in terms of this project, please ask the instructor.
8. The device may not utilize any additional motors or batteries beyond the issued 25 rpm DC Motor (3 V, 0.15 A) or 2 AA batteries.
9. The device may not exceed 1 foot x 1 foot x 1 foot of space. i.e. the device should fit in a box within those limiting internal dimensions.
10. Corrosive chemicals, liquids, flying/airborne machines, and disposable compressed gas canisters are strictly disallowed. Note: While directed air flow is allowed to be used, such as a bellows mechanism, air flow should not be from a finite source or excessively compressed.
11. The cost of the machine (Bill of Materials) and all tools/spare parts required for operation may not exceed $100.
12. The device must utilize a minimum of 6 inches of soldered copper wire track that has curve/bend of at least 30° or more. The track must be utilized by the ball bearing during operation.
13. A minimum of 6 fabrication methods must be used to manufacture the device:
    1. 3D Printing
    2. Laser Cutting
    3. Soldering
    4. Three other methods of the team's choosing. Some examples available in the Maker Space are casting, woodworking, metal machining, water jet cutting, welding, press forming, etc.)
14. The device/steel ball bearings may not cause any damage to the host facility, equipment, or any human or animal. Violation of this rule will result in a disqualification and 0% grade as penalty for producing an unsafe product.

Proving Trial Leaderboard and Grade Impact

15. The percentage breakdown of the Proving Trial grade:

	CRITERIA	**GRADE BREAKDOWN**
1	DEVICE IS FUNCTIONAL	60%
2	DEVICE IS *ALSO* COMPETITION LEGAL	+ 10%
3	DEVICE *ALSO* MEETS TARGET RATE	+ 10%
4	PERFORMANCE/EFFICACY	+ 0–10%
5	SIZE (FOOTPRINT & HEIGHT)	+ 0–10% (or more)

16. 10% of the Proving Trial grade will be decided via the device performance, which is based off of the number of error that occur during the 3 minutes of operation. Each error subtracts 1%, up to 10%. For example, a team that has a perfect run will earn the full 10% of the performance category, whereas a team with three errors would earn 7% in the performance category. A team that experiences 10 or more errors will earn 0% in the performance category.
17. An "error" is defined by a steel ball bearing that runs counter of the intended operation, such as *temporary* jams, skips, falls, misfires, etc. All judgement calls are at the judge's discretion. The judge's decisions are final.
18. 10% of the Proving Trial grade will be decided via how much the team *limits* the device size. The size of the device will be determined by measuring the width, height and length at the longest points. The maximum allowable device dimensions are 12" x 12" x 12"—if a team utilized the full size, they earn 0% in the Size category. For each 1.2" size reduction in any direction, 1% is earned in the Size category. For example, a team with a 12" x 12" x 10.8" device would earn 1% in the size category. More than 10% can be earned in this category (i.e. "bonus" points).
19. If the device malfunctions, breaks, or jams to such an extent that user interference is required, that attempt will be disqualified. The team may make another attempt with permission from the judge. The first successful 3 minute run will be the attempt that is graded. Once a run is initiated, the device must continue until it either completes the requisite 3 minutes, or the device malfunctions, breaks, or jams to such an extent that user interference is required (i.e. the student may not arbitrarily stop the run halfway through just to attempt a better run later). All decisions by the judge are final.