GIFTS: Building Miniature Golf Holes to Teach Iterative Design, Vector Addition, and Playful Prototyping

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Abstract

This GIFTS paper describes a structured miniature golf hole design challenge implemented in a first-year mechanical engineering course to teach vector addition, static forces, and iterative design through a low-cost, hands-on prototyping experience. The activity situates core mechanics concepts within a playful but rigorously structured design task, allowing students to observe, measure, calculate, and revise in real time.

Keywords:
design challenge, experiential learning, vector addition, statics activity, rapid prototyping

Motivation

A persistent instructional challenge in first-year mechanics courses is helping students move beyond symbolic manipulation toward conceptual understanding. Students can often compute vector components correctly yet struggle to explain what those vectors represent physically. As a result, vector addition can feel procedural rather than meaningful. The Miniature Golf Hole Design Challenge was developed to address this gap [1]. Instead of analyzing force diagrams in isolation, students design and construct a system in which force direction and magnitude are directly observable. Each putt functions as a vector with measurable direction and magnitude. Each collision with a barrier or movement along a ramp redirects or modifies that vector. Over multiple strokes, students compute a resultant displacement and compare it to the ball's actual trajectory.

Miniature golf provides an ideal context because it naturally generates multi-stage motion problems. A ball might be struck at 30 degrees, deflect off a 45-degree barrier, then roll down a shallow ramp before stopping short of the hole. Students can see vector redirection, magnitude reduction due to friction, and the cumulative effect of successive applied forces. It becomes visible. Beyond reinforcing statics content, the activity aligns with established principles of experiential learning and early project-based engagement. First-year students benefit from structured opportunities to test predictions, iterate on designs, and observe theory applied in a tangible setting. This activity integrates technical rigor with collaborative inquiry in a single class period.

Objectives

The activity was designed with five learning goals:

1. **Apply vector addition and static forces** to a real-world context by analyzing multiple golf strokes as force vectors with direction and magnitude and calculating their resultant.
2. **Demonstrate systems thinking** by decomposing a golf hole into interacting physical and structural subsystems.
3. **Practice rapid prototyping and iteration** through hands-on design and testing.

4. **Develop teamwork and communication skills** in a collaborative, open-ended problem.
5. **Foster creativity and intrinsic motivation** through a playful, low-stakes environment that encourages curiosity and persistence.

Together, these objectives integrate core topics from a mechanics module with design thinking and experiential learning. The activity situates theoretical knowledge in a concrete, observable system where students can test predictions and visualize outcomes. The activity targets three interconnected categories of learning outcomes: conceptual understanding, design-process development, and student engagement. Conceptually, students apply vector addition and static force principles within a physical system. They record individual putts as vectors defined by direction and magnitude, convert those vectors into components, and calculate a resultant displacement. They then compare the calculated resultant to the observed displacement from tee to hole. Differences prompt discussion of friction, measurement error, and modeling assumptions.

From a design-process perspective, students engage in rapid prototyping and iterative refinement. They must design a functional golf hole, test its performance, diagnose shortcomings, and make evidence-based adjustments. For example, a team may reduce ramp angle after observing insufficient momentum, or reposition a deflector wall to correct unintended rebound. Iteration becomes a visible and necessary part of the engineering process.

The activity also supports systems thinking. Students must consider interacting subsystems—ball, ramp geometry, barrier angle, frictional surface, and structural stability. Rather than isolating forces in abstract diagrams, they examine how these elements work together to influence motion. Affective goals are intentional. The challenge promotes collaborative problem-solving, lowers performance anxiety, and reinforces that engineering design involves experimentation and refinement. Students frequently report increased confidence in discussing vector direction and magnitude after physically observing these effects.

Implementation

The design challenge begins with a brief introduction to miniature golf. Although many students are familiar with the game, instructors provide a short explanation and demonstration to establish shared understanding with a putting green device. A sample putt is performed, and directions are sketched on the board to illustrate how motion can be modeled as vectors. Students work in teams of four to six. Each team receives corrugated cardboard for the base and ramps, narrow wood strips for side walls and deflectors, tape, and supervised access to a staple gun for structural attachment. Golf balls, a putter, measuring tape, and protractors are shared among teams. The limited material set emphasizes creativity within constraints and keeps implementation costs low.

The session unfolds in four structured stages:
1. **Concept Development (10 min):** Teams brainstorm a theme and identify where forces act within their design: ramps, deflectors, obstacles, and frictional surfaces. They sketch the hole layout and label key vectors that represent likely ball paths.

2. **Prototyping (25 min):** Using cardboard and wood strips, teams construct their hole, focusing on one key design principle (e.g., controlling direction with angled barriers or conserving energy on slopes). The instructor prompts teams to predict how the ball's direction and speed will change at each interface.
3. **Testing and Analysis (20 min):** Teams test the hole and record several "putts" as vector quantities with both direction and magnitude. They measure angles and distances to calculate a resultant vector that represents the overall path from start to hole. This reinforces how successive applied forces can be modeled, summed, and analyzed.
4. **Showcase and Reflection (20 min):** Teams play each other's holes, discuss which physical principles most influenced performance, and share one design improvement they would make after testing.

During testing and analysis, teams perform multiple putts and measure approximate direction and distance. Using a chosen coordinate system, students estimate vector magnitudes and angles, convert to components, and calculate the resultant displacement vector. They then compare this theoretical resultant with the actual displacement observed from tee to hole. Discrepancies prompt discussion about frictional losses, imperfect alignment, and modeling assumptions.
In some implementations, the class assembles the individual holes into a collective course, reinforcing community and shared learning.

Assessment and Findings

Assessment includes short reflective prompts and instructor observation. Students complete a brief worksheet where they:

- Sketch their golf hole layout.
- Represent at least three ball paths as vectors.
- Calculate a resultant vector showing cumulative motion.
- Document their physical prototype.

Reflections show that students begin to see the connection between vector representation and physical motion. One student noted, "I finally saw why we add forces by direction; it actually makes sense when you watch the ball's path." Another remarked, "We talked about equilibrium when our ramp angle was too steep and the ball stopped mid-way."

Across multiple course offerings, three consistent outcomes emerged:

- **Conceptual reinforcement:** Students demonstrated improved understanding of vector addition and static equilibrium by relating them to observable phenomena.
- **Iteration and problem-solving:** Teams made quick adjustments to ramp angles, materials, or obstacle placement to refine performance.
- **Team engagement:** The playful, competitive framing created an inclusive atmosphere that encouraged experimentation and peer learning.

Assessment aligns directly with the stated objectives. Students complete a worksheet requiring them to sketch their hole, represent multiple putts as vectors, convert to components, compute a resultant, and reflect on differences between predicted and observed motion. This artifact provides direct evidence of conceptual understanding.

Iteration is assessed through written reflection. Students describe at least one design modification they made, the evidence that prompted the change, and the resulting performance difference. These reflections frequently demonstrate recognition of trade-offs, such as balancing ramp angle to maintain sufficient velocity without overshooting the target.

Instructor observations focus on collaborative reasoning, hypothesis testing, and engagement during iteration cycles. In future implementations, a brief post-activity survey will collect data on perceived engagement and conceptual clarity. Instructors have observed improved verbal explanations of vector directionality and fewer sign errors in subsequent statics assessments. Students often reference the miniature golf activity when explaining resultant vectors later in the semester, suggesting improved conceptual retention.

Transferability and Scalability

The Miniature Golf Hole Challenge can be adapted to any introductory mechanics or design course. It can be implemented indoors with small-scale cardboard holes or outdoors as a larger demonstration. Faculty can adjust focus areas to match course outcomes. The challenge also integrates easily with CAD modeling or physics simulation modules, allowing digital analysis of vector paths prior to physical construction. Because the materials are simple and inexpensive, the activity can be replicated across institutions and class sizes.

Conclusion

The Miniature Golf Hole Design Challenge provides a structured and replicable method for making vector addition and static forces visible and measurable. By embedding mechanics concepts within a collaborative design experience, the activity strengthens conceptual understanding, reinforces iterative reasoning, and promotes engagement.
Students leave the session not only having calculated resultants but having observed them in motion. That connection between mathematical representation and physical behavior is foundational to meaningful learning in first-year engineering.

Anticipated Impact

Introducing this activity early in the curriculum helps students experience design as a process grounded in both creativity and physics. By linking play, experimentation, and vector analysis, the Miniature Golf Hole Challenge makes abstract mechanics concepts visible, tangible, and memorable. The result is a learning experience where students calculate, iterate, and laugh, discovering that engineering design can be both rigorous and fun.

References

[1] M. Lande (2021, June). "Tinkering and Making as a Means to Engage Students Across a 1st Year Introduction to Mechanical Engineering." Engineering Unleashed. Retrieved from https://engineeringunleashed.com/card/2327.