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CRI: Introductory Mechanics Demonstrations with Instrumented Skateboards

Adrian Marquez, University of Illinois at Urbana - Champaign
Griffin Charles Sipes, University of Illinois at Urbana - Champaign

Griffin C. Sipes is a PhD student in the Department of Mechanical Science and Engineering at the University of Illinois Urbana-Champaign (UIUC) with interests in adapted exercise and shoulder biomechanics. He holds a B.S. and M.S. in Mechanical Engineering from UIUC. For the past semester, he has been a part of the Strategic Instructional Innovations Program (SIIP) team in the Mechanical Science and Engineering Department at UIUC, contributing to improving engineering education for undergraduate students.

Melany Denise Opolz, University of Illinois at Urbana - Champaign

Melany D. Opolz is a PhD student in the Department of Chemical Engineering at the University of Illinois Urbana-Champaign, specializing in equine biomechanics and bone chemistry. She holds a bachelor's degree in Chemistry from Cameron University and a Master of Science in Chemical Engineering from the University of Illinois Urbana-Champaign. For the past three years, she has been part of the Strategic Instructional Innovations Program (SIIP) team in the Mechanical Science and Engineering Department at the University of Illinois Urbana-Champaign, contributing to educational advancements in engineering through different projects, including the development of open-access online reference pages and the promotion of an entrepreneurial mindset among early engineering students.

Changmin Lee, University of Illinois at Urbana - Champaign

Changmin Lee is a Ph.D. student in the Department of Mechanical Science and Engineering at the University of Illinois Urbana-Champaign, with research interests in bone biomechanics. He holds a Bachelor of Science degree in Mechanical Engineering from Hanyang University in Seoul, South Korea. He has been part of the Strategic Instructional Innovations Program (SIIP) team in the Department of Mechanical Science and Engineering at the University of Illinois Urbana-Champaign, contributing to the advancement of engineering education.

Thomas Golecki, University of Illinois at Urbana - Champaign

I spent 10+ years in industry as an engineer in structural mechanics and structural health monitoring projects, earning professional licensure as PE and SE. My PhD research focused on the structural optimization of dynamic systems including random loading and vehicle-bridge interaction. Now as teaching faculty, I try to connect course concepts to real-world examples in a way that motivates and engages students.

Dr. Brian Mercer, University of Illinois at Urbana - Champaign

Brian Mercer is a Lecturer in the Department of Mechanical Science and Engineering at the University of Illinois at Urbana-Champaign. He earned his Ph.D. from the University of California, Berkeley, in 2016 and subsequently worked as a research engineer at the Illinois Applied Research Institute before turning to a career in teaching and education in 2018. His technical expertise lies in computational and theoretical solid mechanics, and he teaches a range of courses in these topics, including introductory solid mechanics, machine component design, computational mechanics, and finite element analysis. Brian's pedagogical research efforts focus on developing and implementing effective teaching strategies for large lecture courses and increasing student literacy in using computational tools such as Python and to aid in performing calculations and simulations relevant to engineers.

Dr. Emma Mercier

Emma Mercier is an associate professor in Curriculum and Instruction at the University of Illinois Urbana-Champaign. Her work focuses on collaborative learning in classrooms, and in particular, the use of technology for teachers and students during collab

Dr. Kevin Wandke, University of Illinois at Urbana - Champaign

Kevin Wandke received his B.S. degree in mechanical science and engineering and the M.S. degree in electrical engineering from the University of Illinois at Urbana–Champaign, in 2019 and 2022, respectively, where he is currently pursuing the Ph.D. degree in electrical and computer engineering. He was a member of the SULI Program at Argonne National Laboratory, and an Intern of the Edison Engineering Program, General Electric's Global Research Center. He was a recipient of the Chancellor's Scholarship, the Olesen Award for Excellence in Undergraduate Teaching, and a Mavis Future Faculty Fellow in the Grainger College of Engineering.

Prof. Matthew West, University of Illinois at Urbana - Champaign

Matthew West is an Associate Professor in the Department of Mechanical Science and Engineering at the University of Illinois at Urbana-Champaign. Prior to joining Illinois he was on the faculties of the Department of Aeronautics and Astronautics at Stanfo

Dr. Kellie M Halloran, University of Illinois at Urbana - Champaign

Kellie Halloran is a Teaching Assistant Professor in Mechanical Science and Engineering at the University of Illinois Urbana-Champaign. She holds a BS, MS, and PhD in Mechanical Engineering from the University of Illinois and is currently investigating ways to engage undergraduate students and encourage curiosity and creativity in larger engineering classes.

CRI: Introductory Mechanics Demonstrations with Instrumented Skateboards

Abstract

This classroom ready innovation (CRI) details the construction of and plans for an instrumented skateboard demonstration used in introductory mechanics courses. Topics from introductory mechanics courses (statics, dynamics, solid mechanics) can be difficult for students to conceptualize, which can have implications for persistence in the field, as well as performance in later courses. Such courses can benefit from in-class demonstrations and activities that promote student understanding by grounding topics in real-world examples. High-quality in-class demonstrations can increase student engagement and enjoyment of course content when established best practices (such as connecting to real-world problems and using technology to provide real-time data collection) are followed. Furthermore, active learning improves learning outcomes and lowers failure rates. In pursuit of this goal, we have developed an instrumented skateboard that can connect and demonstrate different topics in statics, dynamics, and solid mechanics introductory courses.There are three different instrumented boards, where each board is instrumented to provide real-time data relevant to the individual course content. For statics topics, the skateboard is instrumented with load cells to allow students to measure reaction forces and compare them to theoretical values. For dynamics topics, the skateboard is fitted with 16 inch bike wheels and motion is tracked via video, which allow students to compare calculations of the speeds and positions of the boards and wheels. In solid mechanics, an aluminum board is instrumented with strain gauges, which allows students to analyze stress using beam theory. Ongoing work is to continue to measure student engagement in these demos and connect demonstrations to learning outcomes.

Introduction

Introductory engineering mechanics courses, such as statics, dynamics, and solid mechanics, form the foundation of many engineering curricula. These courses are traditionally taught in large lecture formats that serve to convey and introduce concepts, which are then followed by smaller discussion sections that reinforce understanding of the concepts. Students are often shown theoretical models in these large lectures, which are abstractly connected to physical phenomena. This approach works to form theoretical understanding but can make it difficult for students to develop physical intuition or connect theory to real-world behavior [1, 2]. These connections are especially important in today's workforce, where engineering graduates must demonstrate problem-solving abilities, critical thinking, and create value for their organizations and society. This set of skills is commonly called the entrepreneurial mindset (EM) and can be fostered in the classroom through the instructional strategy of active learning [1].

Active learning is an instructional strategy in which students are engaged in the learning process through activities, problem-solving, and in-class discussions, rather than receiving information through lecture alone [1, 3]. Extensive evidence shows that implementing active learning in science and engineering courses improves overall student performance and conceptual understanding [3]. However, the efficacy of active learning is dependent on how activities are structured. Lecture demonstrations are most effective when students are required to make predictions prior to the demonstration and compare their predictions with their observations [4, 5]. Without this structure, demonstrations veer from being pedagogically effective [4]. Additionally, in-person demonstrations provide greater conceptual gains over video-based demonstrations when real-time interaction and discussion are incorporated [6, 7].

At a large Midwest university, recent efforts have explored ways to connect theory within statics, dynamics, and solid mechanics courses to real-world situations using active learning principles. The culmination of this work utilizes lecture demonstrations based on instrumented skateboards for reinforcing concepts in statics, dynamics, and solid mechanics. Skateboards provide a physically intuitive system that supports a multitude of concepts across these courses. The repetitive use of this skateboard system allows students to recall and revisit concepts from prerequisite courses as the demonstrations build upon one another. The instrumented boards are designed for volunteers to interact with during a live demonstration to maximize student engagement.

This Classroom Ready Innovation (CRI) presents the development of the skateboard demonstrations across three introductory mechanics courses – Statics, Dynamics, and Solid Mechanics. We describe the design innovation, the connection of the demonstration to each course, fabrication plans, data acquisition, and instrumentation. Engineering drawings for manufacturing are also provided.

System description

The physical system consists of three instrumented skateboard demonstrations for use across three introductory mechanics courses: statics, dynamics, and solid mechanics. The statics skateboard is equipped with load cells between the bottom of the board and the top of the skateboard trucks for measuring distribution of loading. The dynamics skateboard is equipped with 16-inch bicycle wheels and visual markers for tracking rotation. The solid mechanics board is machined from an aluminum plate and is equipped with strain gauges for measuring strain and computing stress.

Applications Across Courses

The statics skateboard (Figure 1) demonstration is modeled as a beam with roller supports so students can predict how vertical reaction forces vary as a rider's position changes on the board. Commercial wheel trainers are fitted on the board's wheels to restrict horizontal motion. Load cellsmeasure force in real-time and can be compared to theoretical calculations.

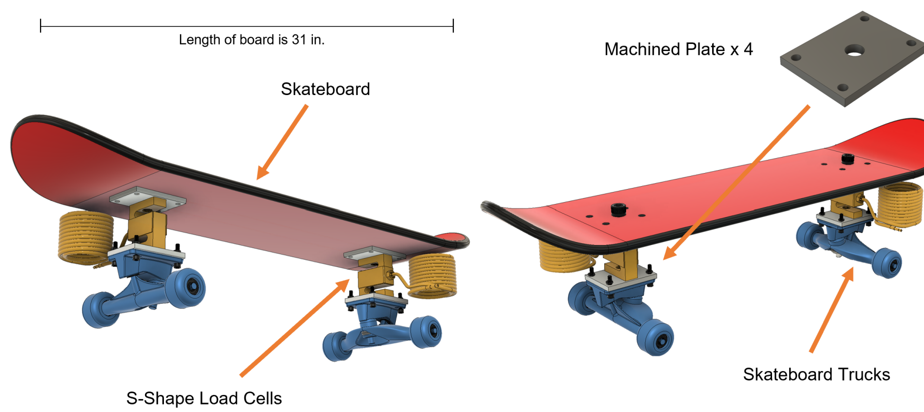

Figure 1: Statics Demonstration CAD Model

The dynamics skateboard focuses on rolling motion, kinematics, and rigid-body motion. The skateboard trucks are fitted with machined steel couplersenabling the use of 16-inch bicycle wheels to allow students to see the wheels in a large lecture hall (Figure 2). Colored markers on the edge and center of the wheel are used to analyze particle motion in videos.

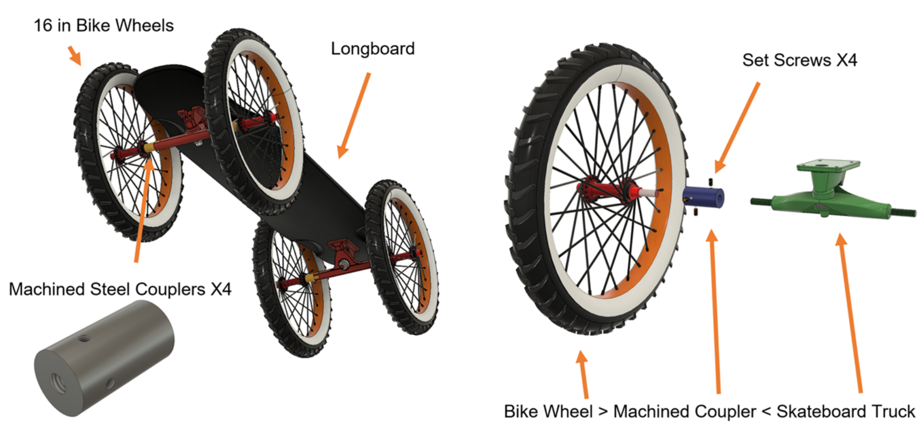

Figure 2: Dynamics Demonstration CAD Model

The solid mechanics board is a machined aluminum skateboard designed to model a beam with pin-roller support (Figure 3). Strain gauges allow students to measure compressive and tensile strains as the board bends under the applied load, which are used to compare experimental results with theoretical bending stresses, moments, and beam deflection.

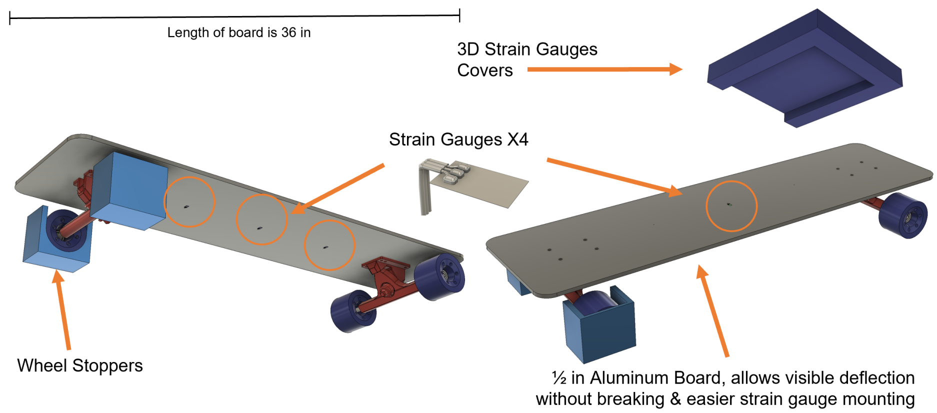

Figure 3: Solid Mechanics Demonstration CAD Model

Materials and Construction

Statics Demonstration Board

The statics demonstration uses a commercial 31-inch skateboard. Between the bottom of the skateboard and each wheel truck, an S-shape load cell is bolted between two machined aluminum plates. The load cell and aluminum plates are secured to the deck and trucks using a combination of the original skateboard hardware and additional bolts (see Apeendix A and B for hardware specifics). Some of the truck material was bore-cut to provide additional clearance for the 1/2"-20 bolt head to fit to finish assembly. Commercial wheel trainers are put on each skateboard wheel to restrict horizontal motion during the demonstration. The load cells are wired into an NI-9181 chassis with an NI-9237 module to connect into a custom LabVIEW file that visualizes and records reaction force data at a specified sample rate (Figure 4). Additional part details can be found in the Appendix (Table 1).

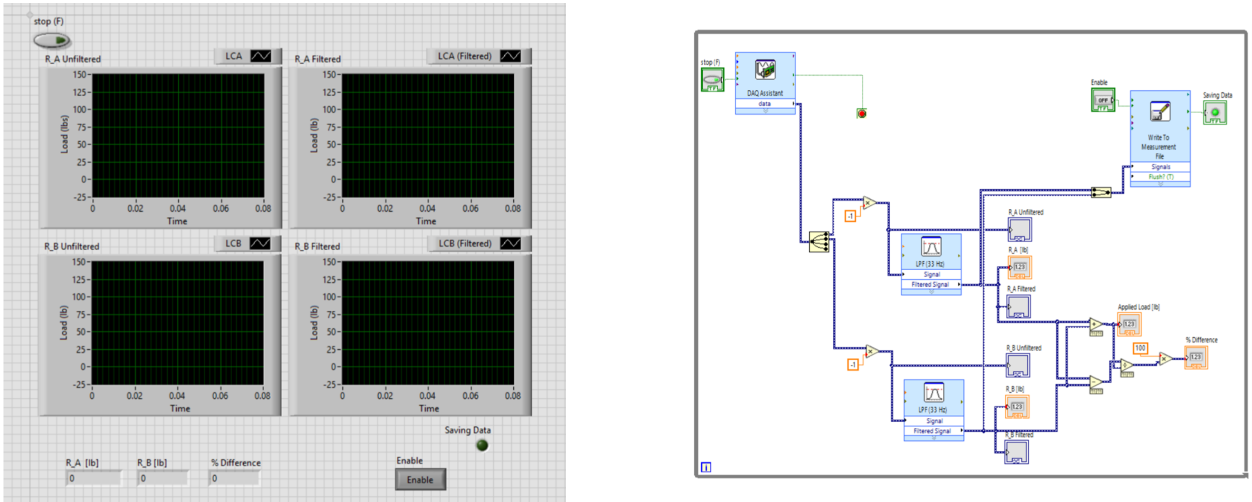

Figure 4: Statics Demonstration LabVIEW Front and Back Panels

Dynamics Demonstration Board

The dynamics demonstration uses a pre-assembled 41 by 9-inch skateboard and four 16-inch bicycle wheels to allow for easier analysis of rolling motion and viewing in large lecture halls compared to smaller skateboard wheels. The bicycle wheels are installed by removing the pre-installed wheels, installing machined steel couplers on the truck axles, and mounting the bicycle wheels. One of the wheels uses colored markers at its center and edge to make path tracking on the Tracker software accurate and repeatable (Figure 5).

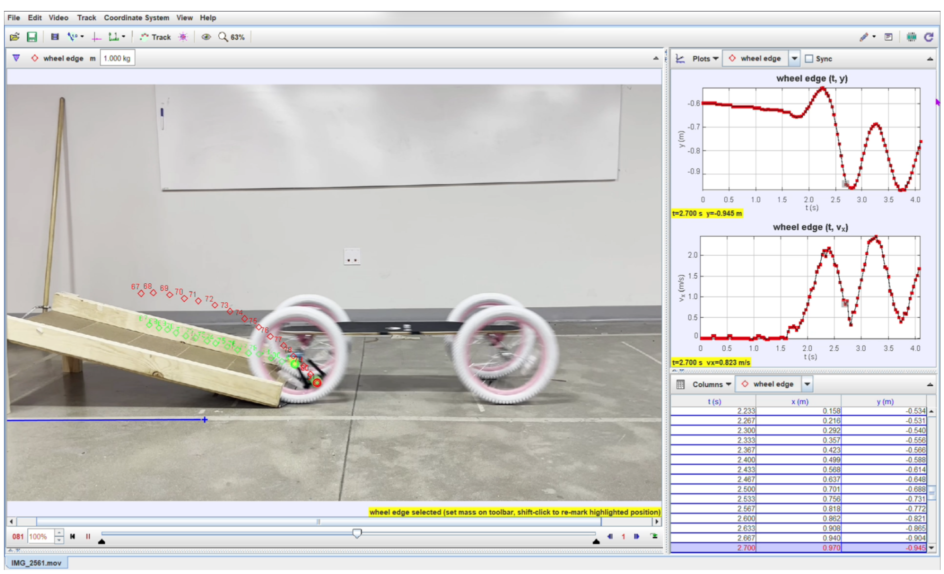

Figure 5: Tracker Example for Dynamics Demonstration

Solid Mechanics Demonstration Board

The solid mechanics demonstration pairs a machined aluminum skateboard with commercial trucks. Four 1/8” 350-ohm strain gauges are spaced at 8-inch intervals (three on the bottom, one top center). One truck is secured with 3D-printed wheel-stoppers. Each strain gauge is wired in quarter-bridge configuration to an NI-9181 chassis channel and NI-9237 input module. A custom LabVIEW file is used to visualize and record live strain data for each pair (Figure 6).

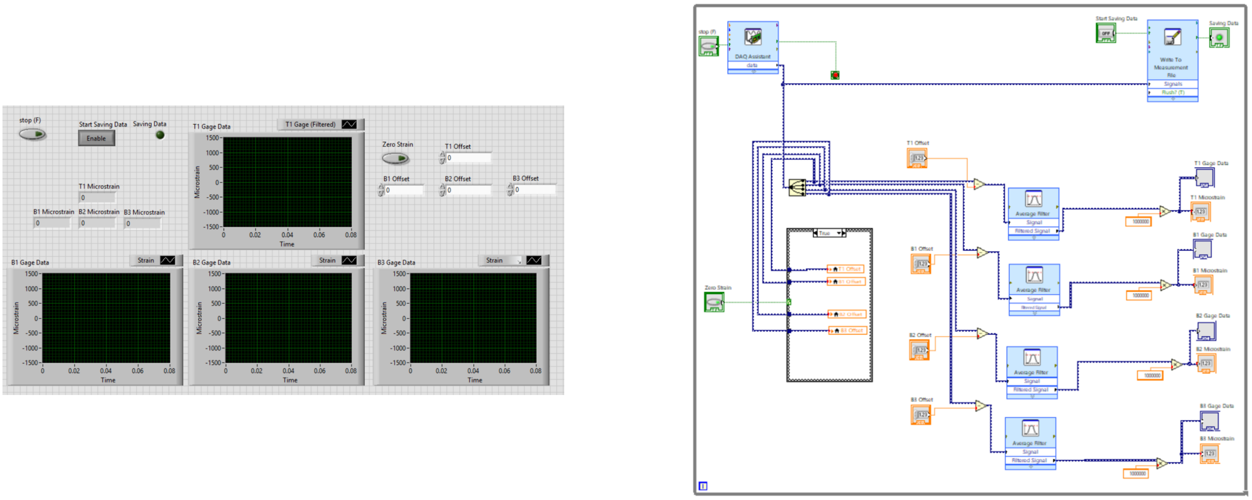

Figure 6: Solid Mechanics Demonstration LabVIEW Front and Back Panels

Demonstration Procedures and Classroom Integration

Each demonstration is designed to be used within lecture. Students are expected to have covered the relevant theory in lecture prior to any demonstration. Each activity follows an active learning structure to improve conceptual understanding following each demonstration.

In statics, students model the skateboard as a two-dimensional beam on two roller pins and calculate the reaction forces at the wheels (Figure 7). The instructor then asks for student volunteers to stand on the skateboard and the LabVIEW module plots the real-time reaction force measurements, which enables students to compare theoretical predictions with experimental data. This comparison reinforces core statics concepts, including equilibrium conditions, reaction forces, and modeling assumptions.

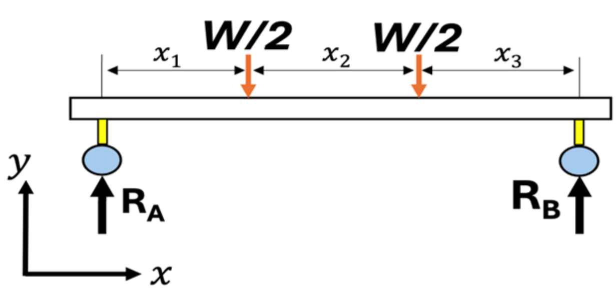

Figure 7: Theoretical Model for Statics Demonstration

In dynamics, the skateboard is configured to roll down a ramp. Students assume a no-slip condition between the skateboard wheels and the ground. The wheels are modeled as solid disks (Figure 8). Students will also assume that there is no energy loss as the skateboard transitions from the ramp to flat ground. Students are asked to calculate the translational speed of the skateboard at the bottom of the ramp by applying energy conservation laws to solve for the initial and final energies. The instructor then performs the demonstration and records a video or presents a pre-recorded video of the demonstration. The footage of the demonstration analyzed with Tracker software, which is used to measure the translational speed of the skateboard at the bottom of the ramp. Lastly, students compare their predicted and experimental values and discuss how well their assumptions aligned with their observations.

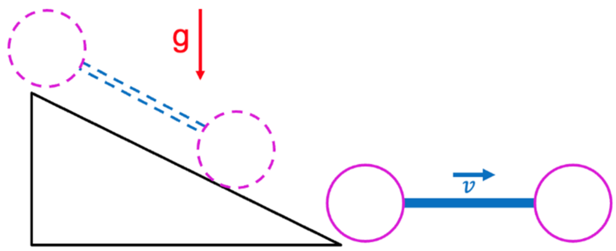

Figure 8: Theoretical Model for Dynamics Demonstration

In solid mechanics, students will solve for the internal stresses and strains within the beam and the overall deflection of the beam (Figure 9). Students solve for the moment as a function of the length of the beam, x. The moment can then be related to the bending stress and strain along the beam. The instructor can then ask for student participants to stand on the board as the custom LabVIEW module plots real-time strain measurements. Students then compare their predicted and experimental values, emphasizing regions in tension and compression, neutral axis behavior, and linear elasticity assumptions.

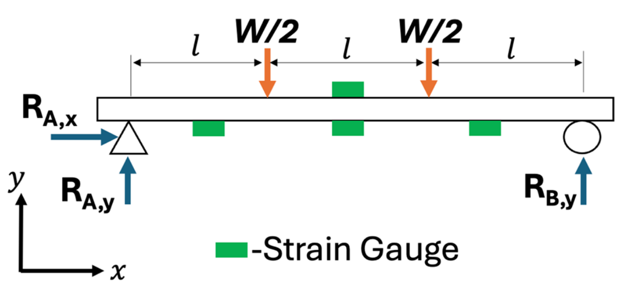

Figure 9: Theoretical Model for Solid Mechanics Demonstration

Each demonstration is designed to be completed in 10-15 minutes.

Instructor Tips and Potential Sources of Error

To minimize measurement errors, zero the statics load cells before each session. In dynamics, manual point selection in Tracker videos can introduce inaccuracies - precise selection is important. For solid mechanics, improper strain gauge installation may cause pre-stress zero offset errors.

Conclusion / Summary of Impact

The skateboard demonstrations aim to reinforce learning across the introductory mechanics courses using familiar demonstrations in statics, dynamics, and solid mechanics. The integration of sensors, data acquisition, and visual analysis help bridge the gap between course theory and real-world behavior. Continuity between demos in all three courses encourages students to recall previous course topics as they build upon them in the next course. Future work includes formal assessments of learning outcomes, expanded instrumentation, and adaptation to other mechanics course topics and mechanics-adjacent courses. Overall, these demonstrations provide a practical and reproducible method for bridging theoretical models and physical intuition in engineering mechanics education.

Acknowledgements

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Appendix (Supporting Materials)

Appendix A: Bill of Materials

Table 1: Budget Summary for Statics Skateboard Demonstration

Item Description	Supplier	Unit Cost ($)	Qty	Total Cost ($)
Pre-Assembled Skateboard	Amazon	39.99	1	39.99
Load Cells (S-Type, 500 lb)	McMaster-Carr	230.14	2	460.28
Material for Aluminum Plates (6061-T651)	OnlineMetals	171.41	2	171.41
1/2”-20 3/4” length Bolt (5)	McMaster-Carr	8.22	1	8.22
1/2”-20 1 3/8” length Bolt (5)	McMaster-Carr	9.59	1	9.59
Skateboard Wheel Trainers (4)	Amazon	20.99	1	20.99
DAQ Hardware (NI-9181, NI-9237)	National Instruments	—	—	—
NI LabVIEW Software	National Instruments	—	—	—
Total				**697.26**

Table 2: Budget Summary for Dynamics Demonstration

Item Description	Supplier	Unit Cost ($)	Qty	Total Cost ($)
Pre-Assembled skateboard	Amazon	62.99	1	62.99
Bicycle Wheels (16 in)	Amazon	47.99	4	191.96
10-32 1/2” length Set Screws (16)	McMaster-Carr	18.25	1	18.25
1”-D 3’-Long Alloy 4130 Steel Bar	OnlineMetals	73.25	1	73.25
NI-DAQ Hardware	National Instruments	—	—	—
Total				**345.74**

Table 3: Budget Summary for Solid Mechanics Demonstration

Item Description	Supplier	Unit Cost ($)	Qty	Total Cost ($)
Pre-Assembled skateboard	Amazon	62.99	1	62.99
Material for Aluminum Deck (6061-T651)	OnlineMetals	171.41	1	171.41
Strain Gauges (350 Ω, 9’, 3 lead wire)	McMaster-Carr	159.96	1	159.96
Strain Gauge Adhesive	McMaster-Carr	101.65	1	101.65
Strain Gauge Installation Tape	McMaster-Carr	152.78	1	152.78
Strain Gauge Surface Conditioner	McMaster-Carr	32.22	1	32.22
Strain Gauge Surface Neutralizer	McMaster-Carr	30.15	1	30.15
Strain Gauge Coating	McMaster-Carr	79.82	1	79.82
DAQ Hardware (NI-9181, NI-9237)	National Instruments	—	—	—
NI LabVIEW Software	National Instruments	—	—	—
Total				**327.49**

Appendix B: Demonstration Drawings

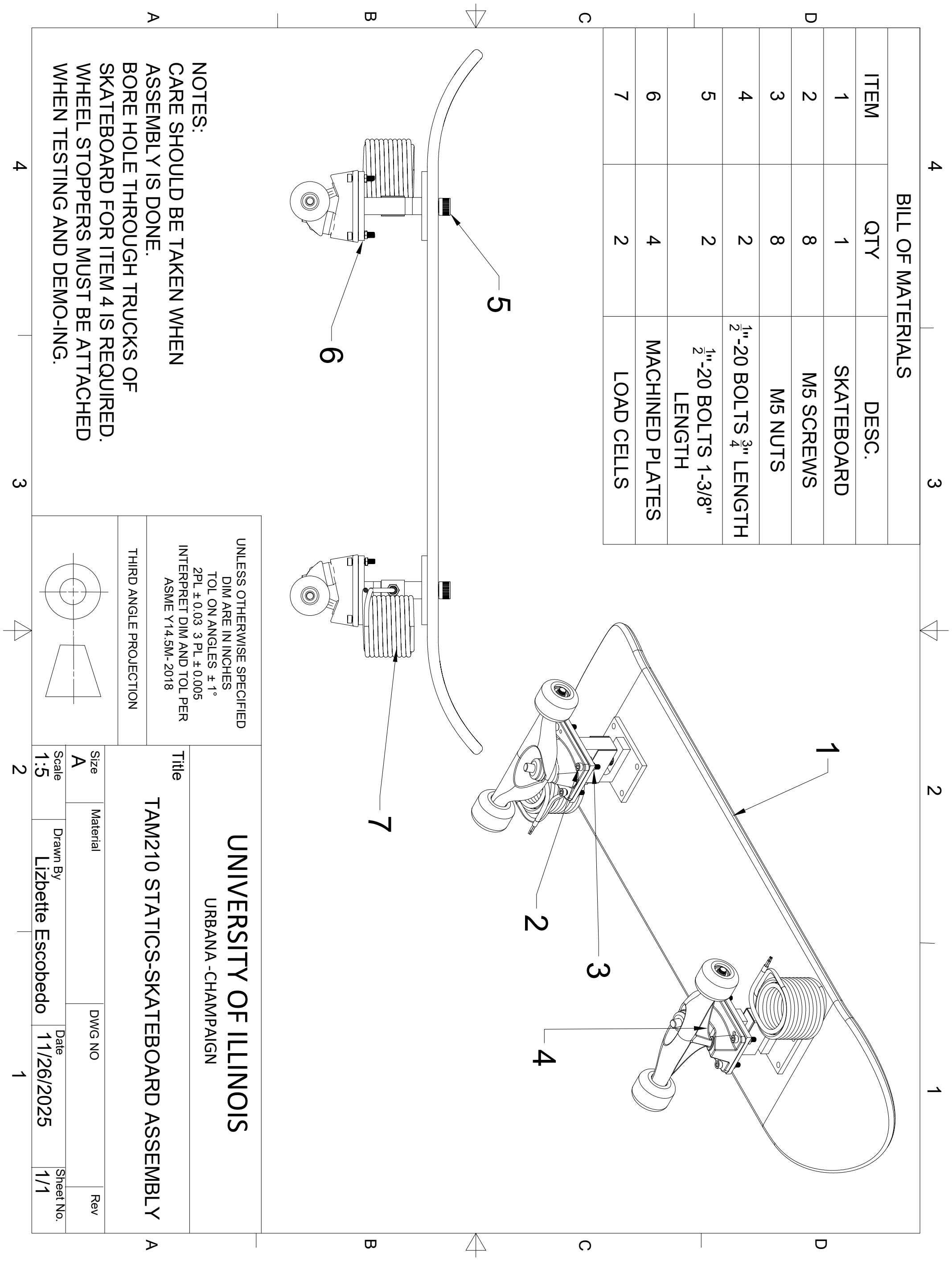

Figure 10: Statics Demonstration: Assembly Drawing

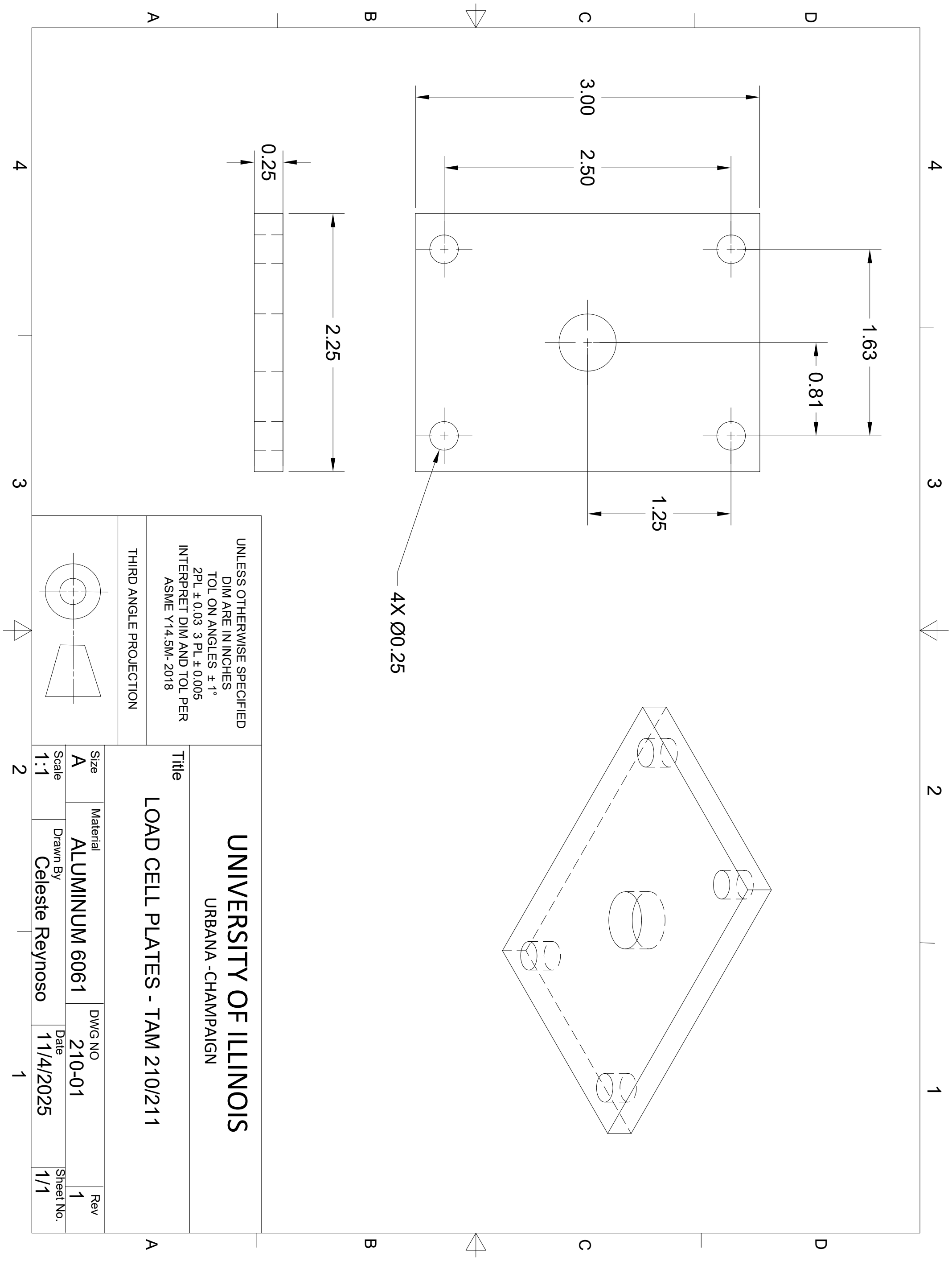

Figure 11: Statics Demonstration: Load Cell Plate Drawing

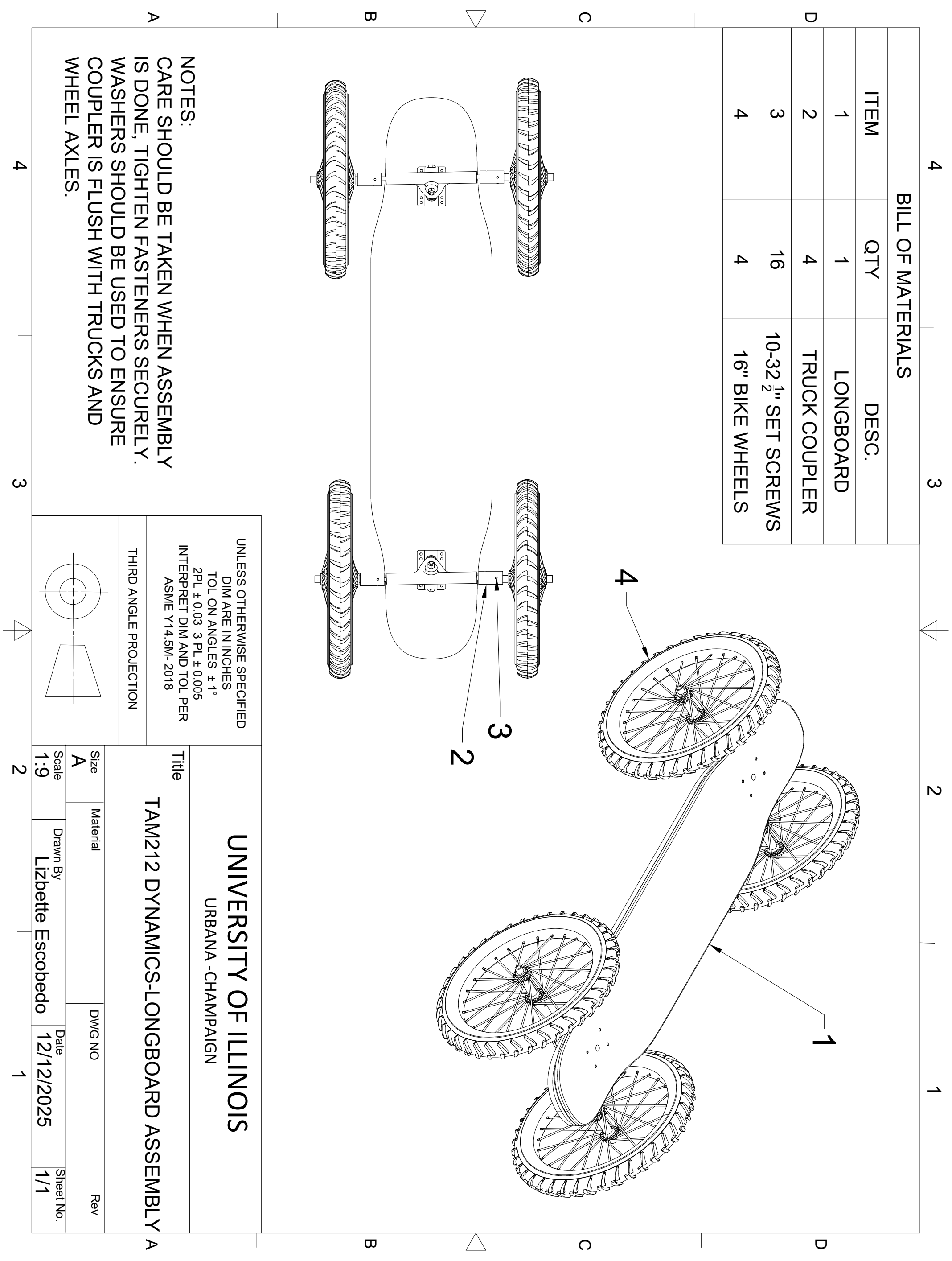

Figure 12: Dynamics Demonstration: Assembly Drawing

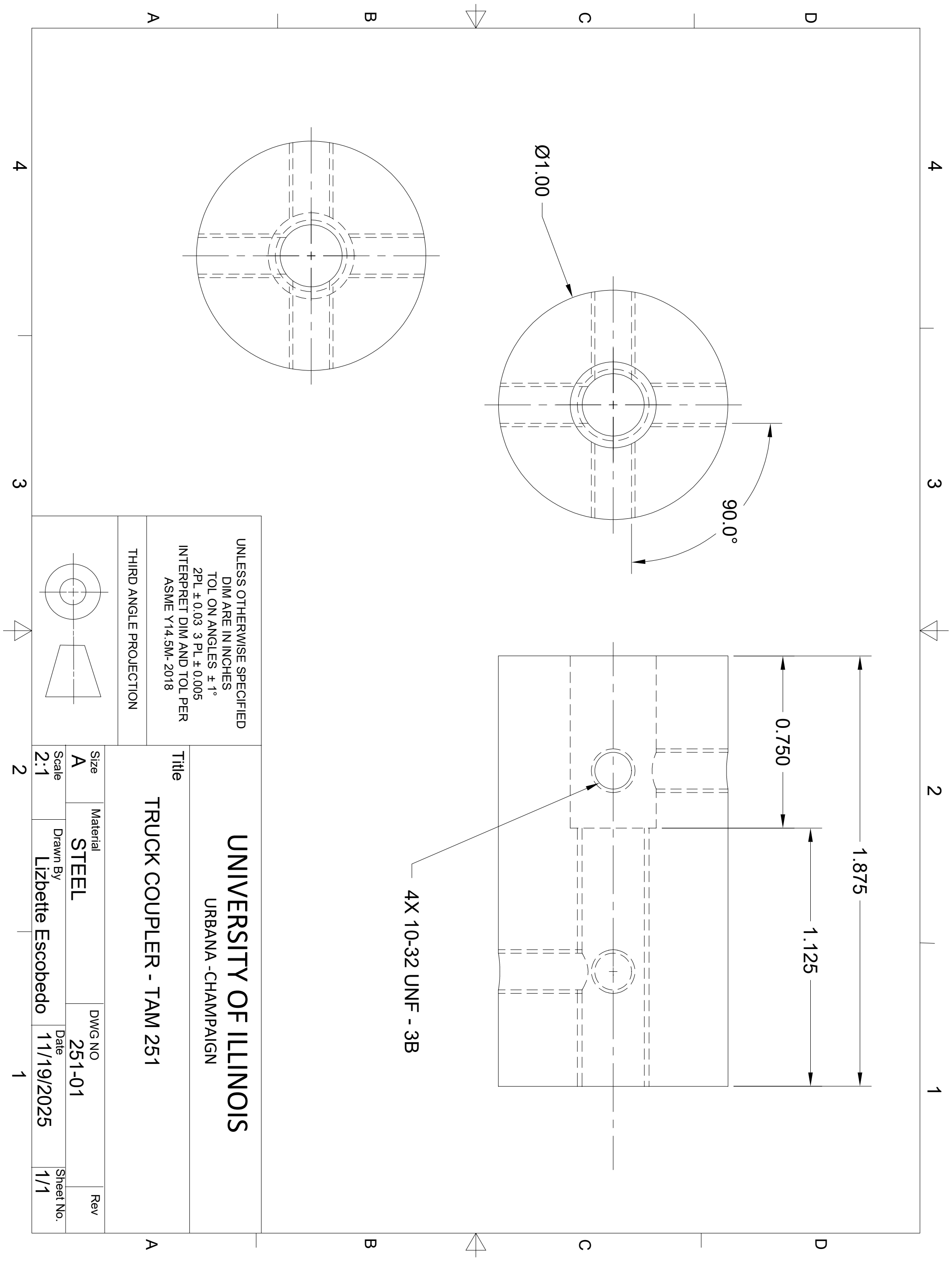

Figure 13: Dynamics Demonstration: Truck Coupler Drawing

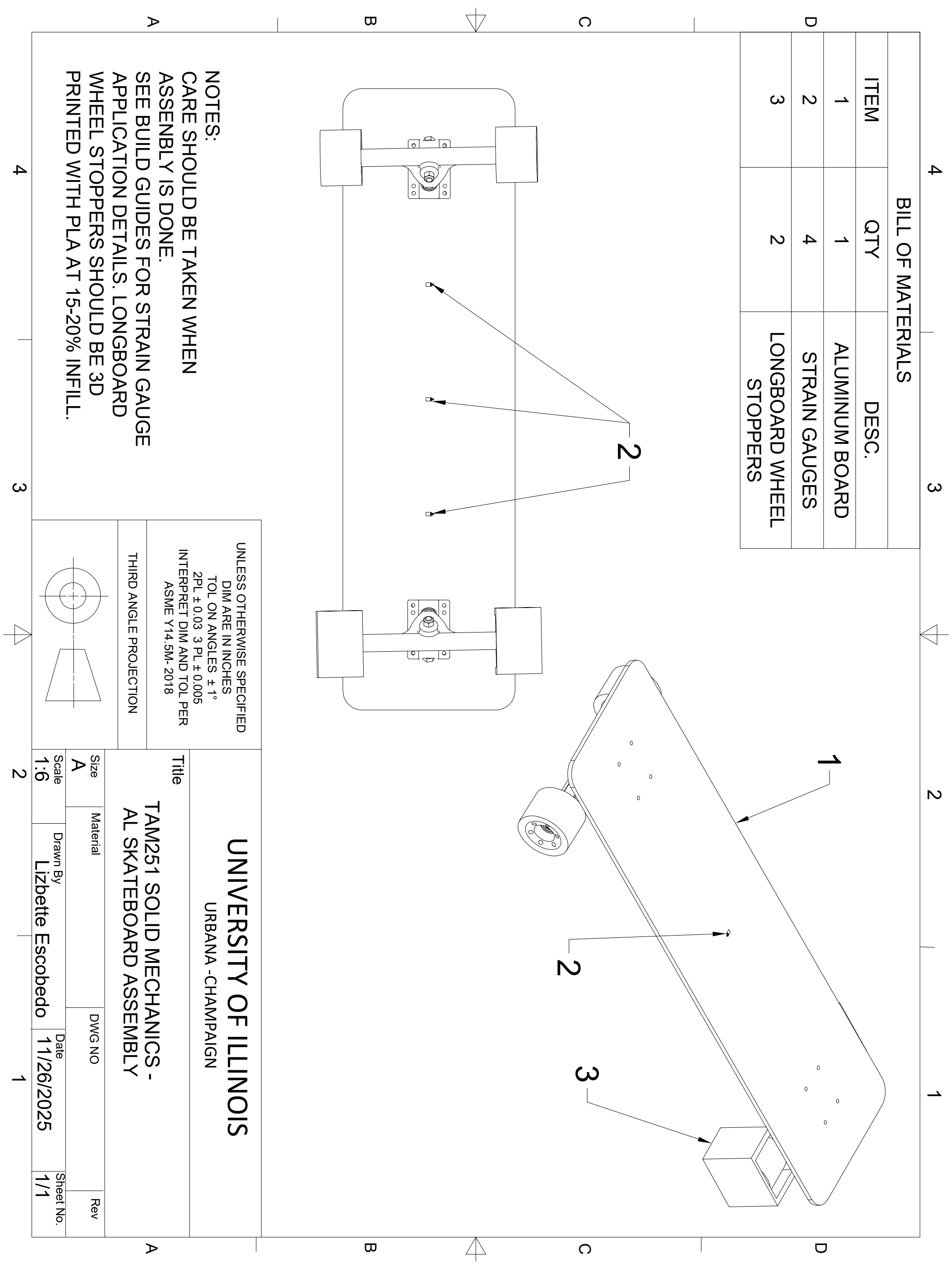

Figure 14: Solid Mechanics Demonstration: Assembly Drawing

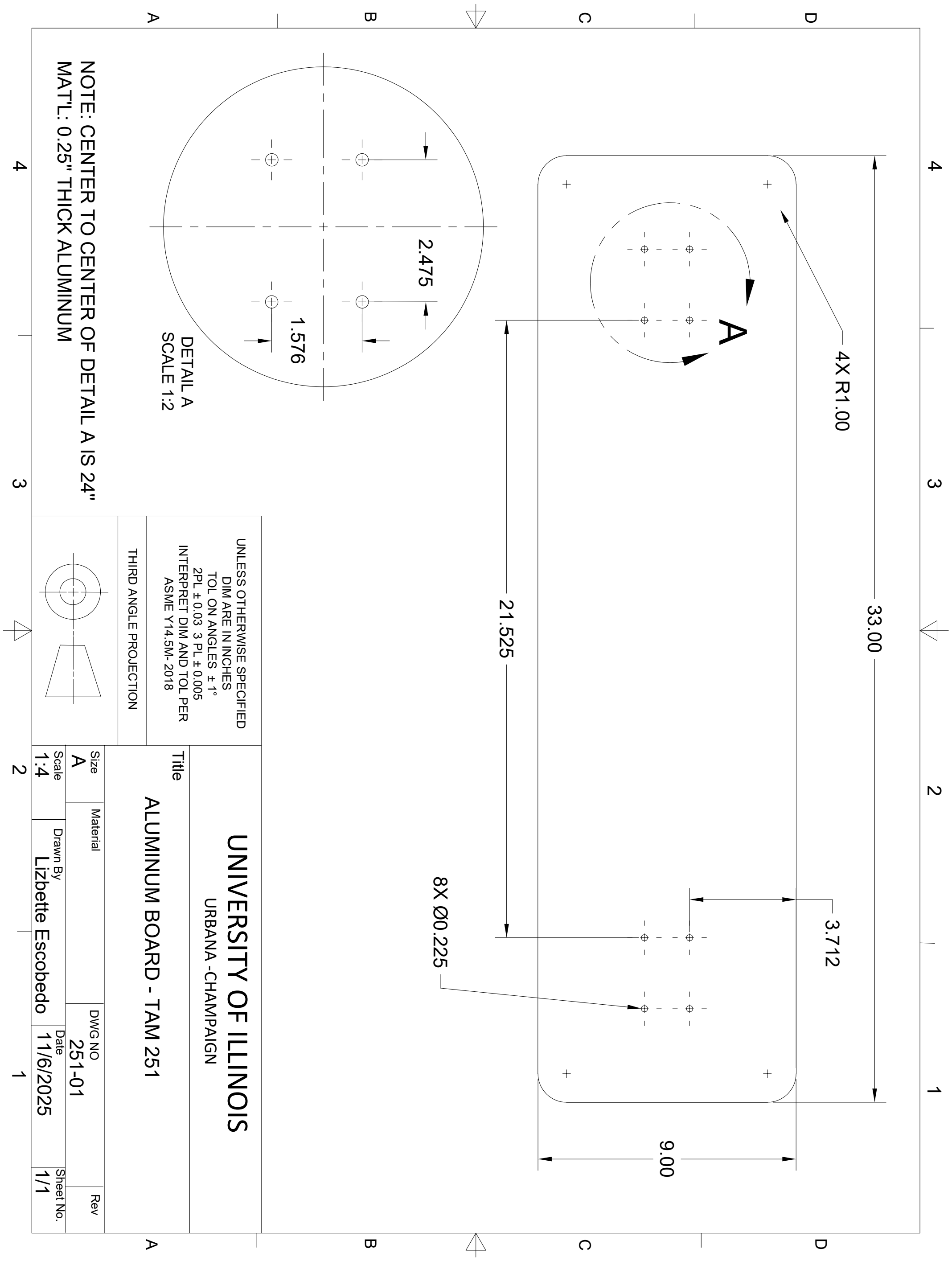

Figure 15: Solid Mechanics Demonstration: Aluminum Board Drawing

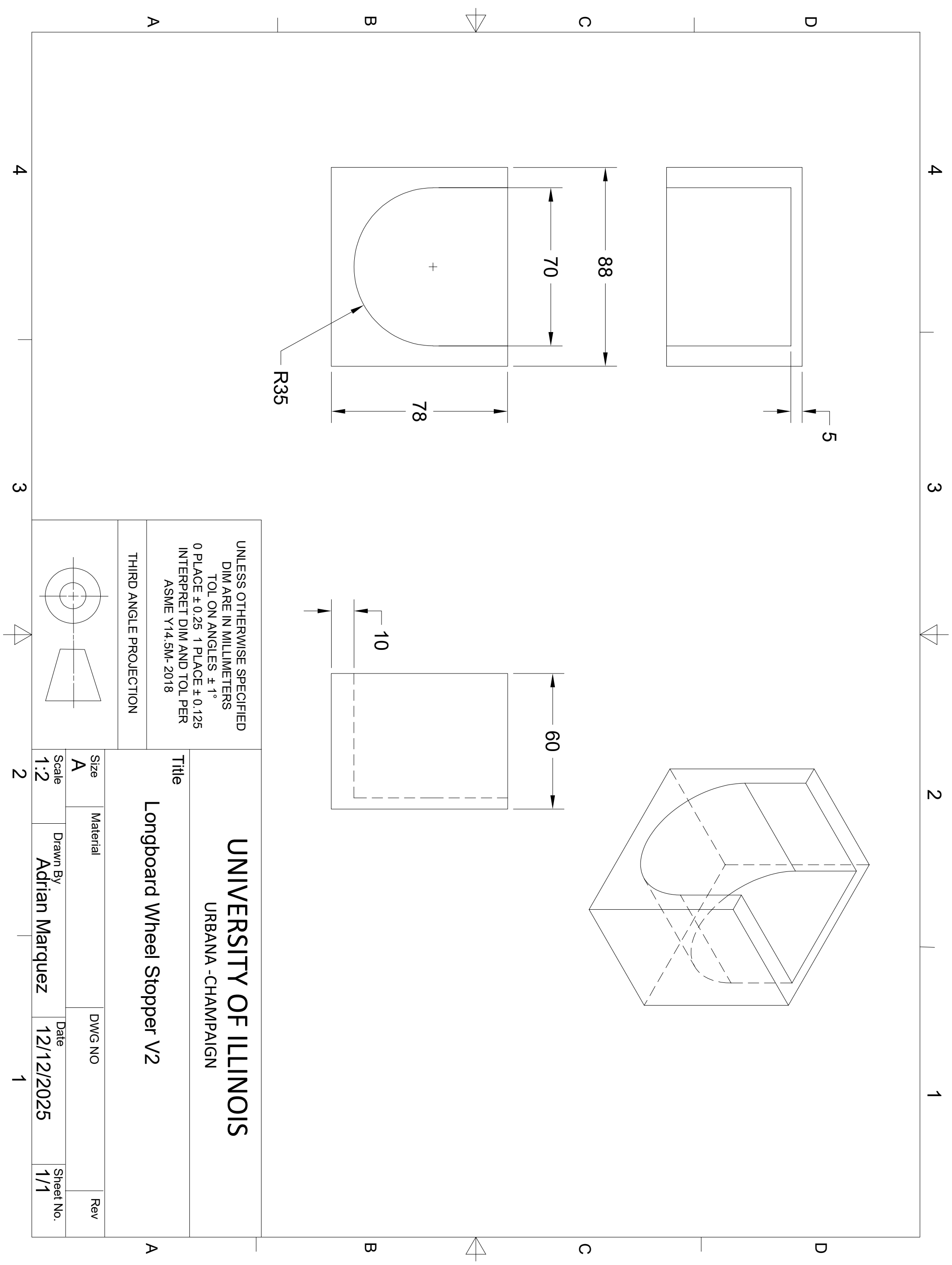

Figure 16: Solid Mechanics Demonstration: Skateboard Wheel Stopper Drawing

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