The Forces of Stage Design: An Interdisciplinary Approach to Teaching Normal Force, Frictional Force, and Design Ethics for non-STEM Majors

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Abstract

This paper presents an innovative lecture and lab for teaching the concepts of normal and frictional force to non-STEM majors through a design activity centered on raked, or inclined, stages. This joint lecture and lab suited a three-hour-long class by alternating between small lectures and lab activities. First, the history of the raked stage was introduced and artistic motivations for designing raked stages were presented. Then, the students measured the weight of 100 g and 500 g masses on an inclined track as a function of the angle of incline. The students were asked to calculate the expected weight as well to compare their measurements and build their critical thinking skills, as well as their intuition for whether a result makes physical sense. The class gathered again to discuss trends they observed and to delve into the governing equations behind these trends. Upon learning about the equations for normal and frictional force as well as how to draw force body diagrams, the students were presented with research papers on the negative impact of performing on raked stages on a performer's body. Lastly, the students answered word problems in groups about designing inclined stages and also considered the ethical impact of designing a raked stage for their performers. Students commented on their improved clarity in learning the material through this blended lecture and lab structure and were further inspired by the activity to tie the lab's experimental setup to their final project in the class.

Keywords

Inclined Plane, Normal Force, Design Ethics, non-STEM majors

Introduction

At most liberal arts colleges in the United States, science, technology, engineering, and math (STEM) courses are often required as part of their core curricula to ensure non-STEM majors build well-rounded science literacy foundations for their diverse career prospects. However, many students who enroll in non-STEM programs may experience science anxiety, decreasing their confidence to succeed in STEM courses. The root of this anxiety may stem from myriad sources, from poor experiences in middle or high school STEM classes to anxiety arising from societal barriers due to the different identities a student may hold.

Yet, Udo et al. found that enrolling students in an interactive, introductory physics course decreased science anxiety for non-STEM majors [1]. While Smith et al. found that most non-STEM majors enroll in STEM courses to fulfill a major requirement, they also found that students enrolled in physics courses take these classes to be hired, perform well, and advance in their future careers [2]. The authors in this work encouraged physics faculty to take advantage of this interest by connecting physics concepts to how the students might apply them in their future careers. Furthermore, developing critical thinking skills is crucial for the advancement of the students' future careers. Wartono et al. found that designing a lesson using the inquiry-discovery learning model, in which students are guided through the process of finding and learning about a physics principle by themselves to better train their mental models, improved the critical thinking abilities of high school students [3]. Glynn et al. suggested instructors should take special effort to connect science concepts to the students' future careers as well, as this increases the students' motivation to continue learning science [4]. Science Education for New Civic Engagement and Responsibilities (SENCER) courses strengthen non-STEM student interest in science through the immediate use of scientific knowledge and methods on matters of relevance to them, as indicated by the SENCER ideals [5]. Therefore, to mitigate the hesitancy toward science courses for non-STEM majors, classes should be intentionally designed to better connect physics concepts to relevant scenarios for the students.

Furthermore, core curricula at liberal arts institutions are designed to prepare students for becoming effective, informed, and ethical citizens in a constantly evolving sociopolitical environment. Teaching ethics to students remains a challenge for many STEM instructors due to its seemingly abstract nature, but nonetheless remains a critical component of a student's preparation for a professional career. For both STEM and non-STEM students, integrating ethics into the topic at hand can be difficult, as the broad, philosophical analysis required to solve ethics problems can contrast with detailed, technical case studies these ethical issues are often tied to. Ermer and VanderLeest developed design norms for evaluating designs for their ethical content and as a teaching tool to reduce these instructional barriers [6]. To reduce the exposure gap to valuing humanistic aspects of design, Van Treuren and Eisenbarth also highlight the importance of social science and humanities classes for engineers [7]. For students in all major programs, there remains a need to develop the critical thinking skills required for making ethical decisions when designing new solutions to relevant issues.

In this paper, we discuss a lecture and lab activity for introducing the concepts of normal and frictional force to non-STEM majors in an undergraduate Physics for the Fine Arts class. By using the context of raked stage design, we tied the importance of these forces to a setting that might be more familiar for the many film and theater majors in the class. The blended lab and lecture style of the class helped students to see the physical trends in real-time, understand both the importance and influence of the physics concept, and connect what they learned to multiple relevant scenarios. Our incorporation of ethical design making for building a raked stage also probed the students' critical thinking skills for ways to balance artistic intention with the safety of the performers that will work on the stage. The best practices learned in this work could also be used for introductory classes for younger students with a penchant toward STEM or in pre-course workshops for students from historically excluded groups in STEM who may have similar hesitancy and low self-efficacy as non-STEM majors.

Lesson Plan and Results

As a Natural Sciences and Mathematics requirement in the Liberal Arts Foundation at Augsburg University, PHY119: Physics for the Fine Arts and its accompanied Lab is a 4-credit course that encompasses a scientific study of sound, light, and the mechanics of structures and the human body in the context of music, the visual arts, and theater. Augsburg's campus is located in the Cedar-Riverside neighborhood of Minneapolis, one of the most diverse areas in the region. 58% of undergraduates are students of color, 55% are female, and 54% are first generation. Our classroom's diversity was a good representation of these demographics. The course meets twice a week for three hours each and typically starts with an hour-long lecture, then a two-hour long activity or lab done in groups of four to six students. This course also meets a Quantitative Reasoning graduation skill requirement. The course discussed in this work was taught in the Spring Semester of 2023 with a strength of 25 students. The students in this course were non-STEM majors from diverse backgrounds, with over half of the students identifying as women or non-binary. Their STEM self-efficacy varied as well, since many students in the class were concerned about their level of preparation to deal with the math being used in the course. This often had to do with their level of confidence rather than their actual ability to handle the math.

Author Kristine Loh was the instructor for the lesson presented in this work and Dr. Moumita Dasgupta was the instructor of record for this course. This lesson was developed as part of Loh's practicum experience in the University of Minnesota Preparing Future Faculty Program. This certificate program assists graduate students and postdoctoral fellows in developing teaching skills by requiring participants to teach multiple class sessions under the guidance of their chosen faculty mentors. Kristine developed the lesson presented in this work inspired by her own background both in ballet and engineering. Lessons designed with an instructor's personal connection to the material can add value to the students' learning experience in similar future classrooms.

At the time of the implemented lesson, the students had already become familiar with the concepts of gravitational and frictional forces. They recognized forces arise from interactions between two or more objects. The class had also discussed the idea of contact and non-contact forces, as well as how force can impact motion. This discussion tied into the introduction of Newton's first and second laws. The lesson objectives were then developed as follows:

1. Learn the origins of “downstage” and “upstage”
2. Recognize what a normal force is
3. Draw force body diagrams for a mass on an inclined plane
4. Calculate frictional force based on the normal force
5. Consider the ethical implications of theater and stage design

In this lesson, we experimented with a different class structure where students toggled between shorter lectures and lab activites. Table 1 below presents the structure of the three-hour class and the purpose for each section.

Table 1: Schedule of the lesson and purpose for each portion of the class.

Time (hr:min)	Activity	Purpose
0:00 – 0:15	Discuss lesson objectives and activity premise	Motivation and artistic context
0:15 – 1:00	Students conduct experiments using the inclined track	Spark curiosity in the students and have them experience the physical phenomena in real-time
1:00 – 1:10	Break	Allow time for questions and for all groups to start at the same time
1:10 – 1:20	Discussion on emerging trends from experimental data	Point out best practices in interpreting data
1:20 – 2:00	Teach concepts of normal force and frictional force in relation to a static object on an inclined plane, how to draw force body diagrams, and relevant equations to calculate these forces	Tie data collected by the students with the physical concepts and use an established model to calculate them
2:00 – 2:15	Introduce the students to research papers that discussed the medical implications of inclined stages	Connect their learning with relevant applications
2:15 – 3:00	Complete lab worksheet, which involved word problems and a design ethics question.	Provide time for questions; cognition and metacognition

To provide context for the students, the class began with an introduction to raked stages and their historical importance. A raked stage is a theater stage that slopes upward and away from the front of the stage, such that the audience gets a broader view of the people or items on the tilted stage. The origin of the terms "downstage" and "upstage" for the front and back of the stage, respectively, arises from historical stages being tilted downward toward the audience, while the audience was evenly distributed on flat ground. Modern raked stages are primarily in European theaters, while some theaters in the U.S. still use raked stages for artistic means. We presented the following quote from Mark Abram-Copenhaver, the Artistic Director for the South Bend Civic Theater in Indiana, who intentionally included a rake stage in the production of *Cat on a Hot Tin Roof* [8]:

"A raked stage allows for attractive visual composition of the actors and the scenery in addition to making it possible for the actors who are upstage to be easily seen. [...] But a rake can serve another purpose as well. You may already have thought about the fact that this stage space looks a little bit precarious to walk on. Making the stage a challenging space for the actors/characters to move in is a device used by the director and set designer to **cause the physical world of the production to reflect the inner struggles of the characters.** Big Daddy's house is not an easy place to live in for any of the characters in this play. By raking the stage the director and designer have made the **psychic and emotional challenges of the story a tangible part of the environment for the audience**."

At this point, the students recognized the rationale for building a raked stage despite modern theaters having their seats stacked vertically. To place the students in the position of being future artistic directors themselves, we then transitioned to the first part of the lab activity, which simulated the construction of a raked stage at different angles of incline. The students were asked to imagine that they were stage designers and to determine how much force their raked stages could withstand depending on the angle of the stage. As shown in the schematic in Figure 1, we used materials typically found in physics labs to build the experimental setup. With a height-adjustable track attached to a retort stand, the students could change the angle of the track by simply changing the height at one end. The students then placed a scale on the track and measured the weight of either a 100 g or a 500 g mass as they changed the angle of the track.

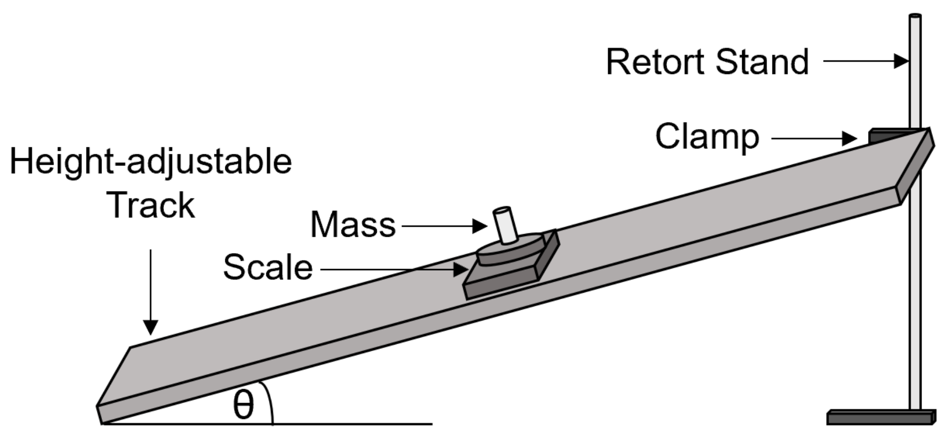

Figure 1: Schematic of the experimental setup, which used a height-adjustable track to rest a scale at different angles of incline, θ.

First, the students were asked to measure the weight of a 100 g mass while the scale was on a flat surface, or at an angle of 0°. This step was to account for any errors in the exact weight of the mass or to determine if they needed to swap out any pieces of their experimental setup. Figure 2 shows the experimental setup in the classroom. To measure the angle of incline for the track, the students used an angle indicator, which had minor ticks for each degree of inclination. Typically, one student adjusted the height of the track while another observed the angle indicator and notified the other student when the track should be kept at a certain height. The scale and mass were then placed next to the angle indicator.

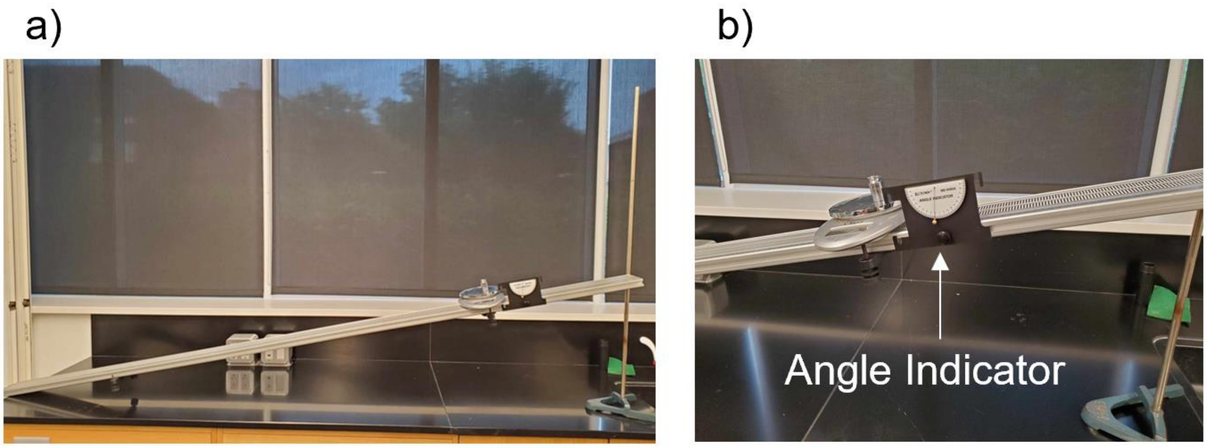

Figure 2: a) Full photo of the experimental setup. b) Close-up photo of the scale on the track with a 100 g mass resting on it and an angle indicator next to the scale showing an incline of 10°.

After the students completed the experimental setup for measuring the mass at an incline of 10°, they were asked to record the scale readout in their worksheet, as shown in Table 2. Many students were surprised to see that the scale was no longer reading 100 g, but instead showed a lower value. They were then asked to continue changing the angle of the track to 15°, then 20° and record the scale readout at each angle change. Once they recorded all of their experimental values, they began calculating the theoretical changes in the measured weight of the mass as a function of the track's angle. As shown in the full instructions in Appendix A, they had to multiply the measured mass when the scale was flat (m_0) by the cosine of the track's angle of inclination. Because some students were using their phones for these calculations while others had scientific calculators, they were all reminded to be mindful of the units in their calculations. One group of students found a large error in their calculations due to their calculator's angle setting in radians, instead of degrees.

Table 2: Experimental measurements of the mass depending on the angle of the track, theoretical calculations of the mass depending on the angle of the track, and the calculated difference between these values for comparison.

100 g Mass			
Angle	Recorded Mass (g)	Calculated Mass (g)	Difference in Mass (g)
0	m_0 =		
10	m_{10} =		
15	m_{15} =		
20	m_{20} =		

Upon completing the first two columns of Table 2, the students were asked to calculate the difference in these values and record them in the third column of the table. One group of students noticed a consistently large difference, on the order of 20% difference, and found that their retort stand was about 10 inches too short for them to get accurate angle measurements. After moving to the correct setup, they were able to get more accurate results and recorded smaller differences in the mass. Having a visual representation of the table to directly compare numbers helped the students to troubleshoot more easily and be more careful with their measurements.

Often, if a student experiences science anxiety, their priority in conducting these lab activities is to complete them as quickly as possible, even if their results do not make physical sense. Both Berry et al. and Hodson discussed this trend for students in science classes, including those who do not experience science anxiety. They found that for lab activities that are highly specified and not inquiry-based, the students' main goal is to complete the lab as soon as possible and ignore discrepant results to finish quickly [9], [10]. The scaffolded completion of this table guided the development of critical thinking skills and gave the non-STEM students a framework for how to check for discrepant results in the future. This visual representation can also reduce science anxiety and increase self-efficacy, as seeing small differences between the measured and theoretical mass could confirm that the students were completing the experiment correctly. Upon completing the table for the 100 g mass, the students then repeated these steps for the 500 g mass. An example of a student group's results is shown in Figure 3.

100 g Mass			
Angle	Recorded Mass (g)	Calculated Mass (g)	Difference in Mass (g)
0	m_0 = 100 g	100	0
10	m_{10} = 98 g	98.48	.48
15	m_{15} = 96 g	96.59	.59
20	m_{20} = 94 g	93.96	.04

500 g Mass			
Angle	Recorded Mass (g)	Calculated Mass (g)	Difference in Mass (g)
0	m_0 = 500 g	500 g	0
10	m_{10} = 487 g	492.4	5.4
15	m_{15} = 476 g	482.96	6.96
20	m_{20} = 470 g	469.84	.16

Figure 3: Example results from a student group for both the 100 g and 500 g masses.

Once the students completed the two tables, they discussed the sources of the differences in mass that they recorded. Some students noted that the large size of the track prevented them from setting the track at precise angles. Others found that the security of the scale on the track influenced the recorded mass. The goal in asking the students where these errors came from was to encourage the students to think about ways to improve their measurements, if they could be improved. For the group of students who had to switch out their retort stand, they noted that they would not have considered switching out their experimental equipment had they not been tasked to consider what the recorded mass should have been.

Then, the class came together to discuss the main observations from the first part of the lab. The key trends were that the measured mass decreased with increasing angle, the change in mass with changing angle was larger for the heavier mass, and the general trends were the same for both masses. To better explain why the students observed these trends, we presented the problem in a more common context in Minnesota: skiing. Given the same quality of snow (same amount of friction), why do downhill skiers move faster than cross-country skiers, who are skiing on flat ground?

To further simplify the problem, we looked at the force balances for a box on a flat surface and a box on an inclined surface. The students gathered in their lab groups to determine the forces acting on the boxes for them to stay stationary. The goal of this exercise was to teach them that for a box to be stationary, all acting forces must sum to zero. As exemplified by the diagram of the flat, stationary box in Figure 4, which was shown to the class after regrouping, the students recognized that for the box to have a net force of zero, there must be some force that is acting against the downward gravitation force. The depiction of the force body diagram was used to inform students that the scale readout they were recording was the normal force.

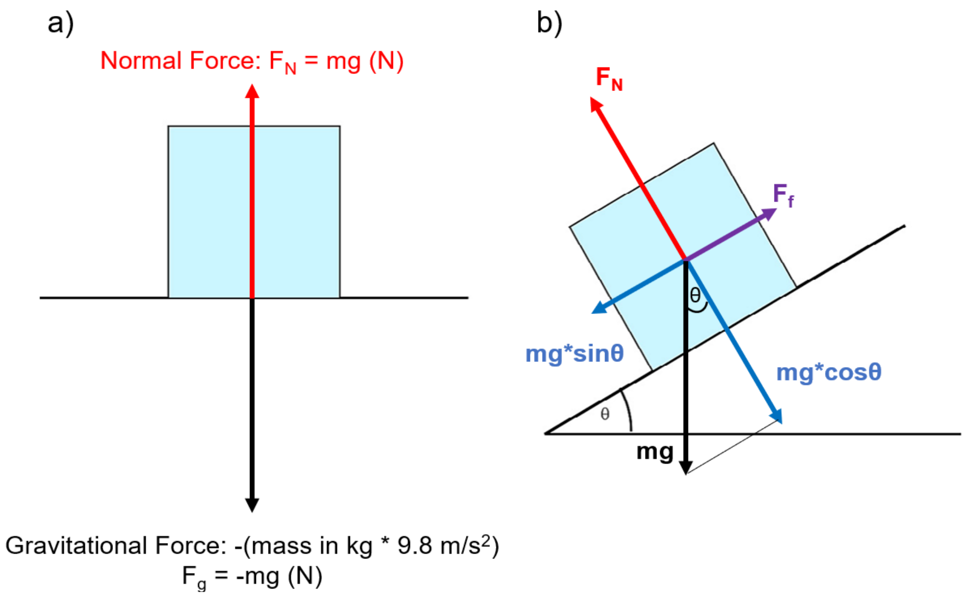

Figure 4: Force body diagrams of a flat, stationary box and an inclined, stationary box used to present the concept of normal force balancing gravitational force.

The students were able to grasp the concept of the normal force quickly and also made connections to pop culture references to improve their understanding. One student asked, "what happens if there is no normal force?" and was better able to understand the result when they could connect the concept of normal force to characters in movies or TV shows that fall through surfaces that cannot hold their weight. We also connected the concept of the normal force to a dancer's balance, as they must counteract the gravitational force acting on them in order to stay stationary in a certain pose.

We then introduced the students to the forces acting on the inclined box, including frictional force and normal force. Most students struggled with the derivation of the sine and cosine relationships, but were able to apply the equations in the second part of the lab activity later. Despite this hesitation, they were still able to recognize that measurements they were recording in the first part of the lab were the normal forces acting on the mass. On a flat surface, this normal force is just equal and opposite to the gravitational force or weight; on an inclination, since the normal force is still acting perpendicular to the surface, it is no longer equal to gravity but to a portion of the gravitational force. After the presentation of the direct relationship between normal force and frictional force, both arising due to the presence of a surface, the students were also able to better understand why downhill skiiers move faster, as they are experiencing less frictional force at steeper angles.

We then transitioned to discussing the ethical implications of performing on raked stages and other scenarios that the students could better relate to. We presented two medical studies on the impact of doing various tasks for actors on raked stages and highlighted that dancers on raked stages often experience more knee and hip injuries due to the increase in ground reaction force when the dancer lands on the raked stage [11], [12]. We also presented a study on the biomechanical impact on women who wear high heels, and showed that the women who regularly wore high heels experienced more force on their knees when walking [13]. Lastly, we informed the students of the balance between protecting their dancers' physical health and achieving the artistic goals of the stage production through the inclusion of a raked stage.

To complete the second portion of the lab activity, the students gathered into their groups again and answered word problems together. First, they were asked to draw a force body diagram of a mass on a 15° incline and to label all of the forces. Then, they were asked to solve a word problem that involved stage design decisions. The students had to determine the maximum number of performers that can stand on an inclined stage that can only withstand 5000 N of normal force. While the calculation resulted in 8.5 performers, it is important to note that all of the students knew to round down instead of up.

Lastly, the students were asked to place themselves in a future leadership position and imagine themselves as stage directors, producers, and leaders in their fields who have to make decisions that impact the actors and other artists they will work with. The final question of the lab activity was based on the engineering design method: given certain criteria and constraints, what are the best design options? The students were asked to choose the largest tilt angle of a raked stage that they would design and explain why. Despite the variance in the angle that the student groups chose, as shown in Figure 5, they all responded assuming the performers' health were constraints in their design. Interestingly, the choice of angle ranged from 0° to 30°, but the rationale for these choices all centered on protecting the artists and their health. The variance in the choice of angle could also be due to the diversity of students in the class, as they had varying exposure to theater arts and might have chosen steeper angles if they were not as familiar with performing on stages.

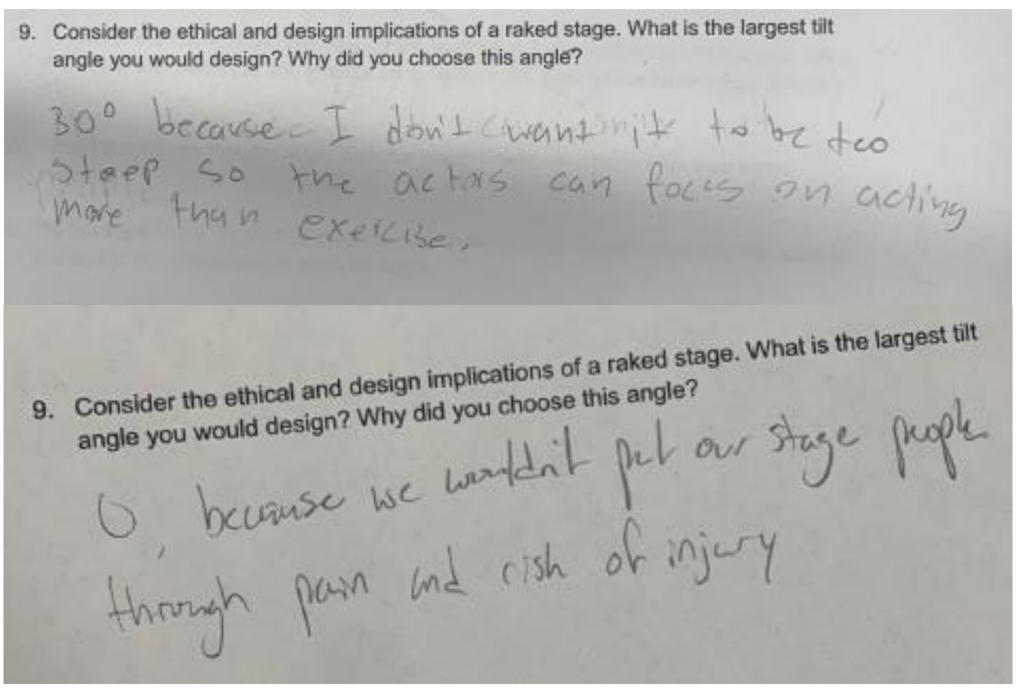

Figure 5: Varied responses to the last question of the lab activity, which asked students to consider the ethical implications of raked stages. The first response says, "30° because I don't want it to be too steep so the actors can focus on acting more than exercise." The second response says, "0, because we wouldn't put our stage people through pain and risk of injury."

Discussion

Overall, many students commented that the blend of the lecture and lab in this lesson helped to clarify their learning. They enjoyed seeing physical trends in real-time first, then delving into the derivation of these phenomena and the governing equations behind it. The format of this lesson aligns well with the learning cycle of exploration, invention, then application developed by physicist Robert Karplus and co-workers. The learning cycle is an instructional strategy for focusing on hands-on experiential learning [14]. The learning cycle allows students to first learn through their own spontaneous reactions to a new situation with minimal guidance (exploration). Then, a new concept or principle is defined to help the students answer their own questions that they developed in the exploration phase (invention). Finally, the students find new uses for the concepts or skills invented earlier (application). This model has been shown to enhance student learning, confidence, and critical thinking [15]. Furthermore, the students' responses to this learning framework agree with the results of Wartono et al., as the inquiry-discovery learning model implemented in this joint lecture and lab heightened the students' curiosity, which moved them to engage more actively in the class [3]. This method of active learning encouraged the students to consider why the trends they observed experimentally differed from their expectations. It was easier for the students to answer a question that they had developed in their head during the lab than to try to process new information and then connect it to something that they could experience physically. This form of active learning can help students identify misconceptions and restructure their mental models [16].

Although some students found this lesson to be more engaging and effective, others questioned the need to have an ethics component. One student was initially resistant to the final question in the lab activity, asking why a question like this was relevant in a physics class. This gave us, the instructors, the opportunity to then explain how science and the people conducting it are intimately connected, and the importance of considering the ethical implications of our designs. Although most engineering students are familiar with the importance of ethical decision making and the tangible consequences of engineering decision-making on the people that use the innovations, as indicated by the ABET student outcome for recognizing the ethical and professional responsibilities in engineering situations [17], non-STEM majors might not be as aware of this aspect. After reiterating to the student that they can use the science and math that they learn in this class to make important artistic decisions in the future that ensure the safety of the artists they work with, they genuinely answered the lab question.

As one of the primary goals of this class is to improve the self-efficacy of non-STEM majors through their increased interest or curiosity in physics, we believe this lesson was successful in achieving this goal as a group of students used this experimental setup as inspiration for their final project. The final project for this course was to demonstrate the integration of physics and art in a tangible deliverable, and one group of students studied the influence of friction from different colors of paint on rolling balls down an inclined track. As shown in Figure 6, the students produced artwork while studying the variances in both frictional and normal forces as they changed the colors of paint, the size of the balls, and the angle of the track.

Figure 6: Artwork made by coating balls of various sizes and shapes (including stress balls and golf balls, as indicated by the hexagonal pattern from the golf ball), and rolling them down an inclined track. The students measured the velocity of the balls as a function of the track's inclination angle and the color of paint.

To expand on this lesson in the future, additional word problems can be added depending on the students in the class. For introductory classes for STEM majors, additional assessments on eliminating sources of error can be added. Furthermore, students in materials science classes can experiment with different materials below the mass to determine friction coefficients on their own instead of being presented with assumed values. For both non-STEM and STEM majors, additional word problems that highlight inclusive design can be added. For example, students can be asked to calculate the maximum angle of incline for a performer in a wheelchair to stay stationary assuming their weight and a coefficient of friction.

As this lesson is a work-in-progress, future iterations could add additional discussion to clarify the difference between weight and mass. Mass, an intrinsic property of an object that should not change with external stimuli, differs from weight, which considers gravitational force. To dispel misconceptions, the instructors should note that the scale readout indicates weight, not mass, despite the readout listing the unit as grams. Confusion may arise from the students as the values they record also use the unit of grams, but it is important to distinguish the difference between how a scale measures weight and the inherent mass of the object they are working with.

Moreover, iterations of this course in the future could begin the course using the community cultural wealth model pioneered by Yosso [18]. This model highlights the wealth students bring to the classroom and shifts the view of the student away from them being in a "deficit" state of developing skills to one where the individual student is seen as inherently bringing in an abundance of personal and community resources. Beginning courses with this mindset will also remind instructors to leverage their students' abilities and assets to mutually benefit the whole class. Leung et al. supported the community-oriented style of learning for teaching math courses, as centering the students' perspectives of what is a relevant math problem and decentering the

STEM professional's point of view both strengthens the value of the community of inquiry and invites students to be stakeholders in their own learning. Authentic exercises and examples in the class, from the point of view of the student, not the instructor, improved the community of the classroom and appreciation of the subject [19]. For Physics for the Fine Arts, the course could incorporate lessons designed in collaboration with the students, who have much more experience in the fine arts than the instructors do. Using the framework presented in this paper, students in the class could build off their lived experiences and inspiration to create physics lectures and labs that are authentic to them. Not only will they enhance their learning by determining the best way to present the artistic motivation that they bring, but they will also create more personal ways to remember the physics concepts tied to their lesson.

Lastly, future classes could incorporate pre- and post-course assessments, such as the SENCER Student Assessment of their Learning Gains (SALG) to investigate student attitudes and perceptions of their self-efficacy both before and after taking the course [20]. A physics attitude scale could also be implemented to gauge the students' improvement in learning and interest in applying physics to their future careers [21].

Outlook

The goal of this joint lesson and lab was to introduce the concept of a normal force in an engaging, memorable way for non-STEM majors with a focus on the fine arts. We found this lesson design on the physics of the raked stage to be successful, as many students felt that the material was more clear to them when presented in this fashion. While this was an introductory course, many of the lessons learned in developing this activity can be applied to classes for STEM majors as well, namely the importance of using relevant scenarios and case studies to motivate the students. Furthermore, having the students make ethical decisions as future leaders in their fields can encourage their interest in physics and remind them of the importance of building these STEM foundations.

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Kristine Loh (she/her) is a PhD Candidate in Chemical Engineering at the University of Minnesota (UMN) co-advised by Professors Vivian Ferry and Uwe Kortshagen. As a National Science Foundation Graduate Research Fellow and a College of Science and Engineering Fellow, she studies nontoxic nanomaterials and their applications in renewable energy technology, namely agrivoltaic systems. As a graduate student, she has continued her passion for education through the completion of the UMN Preparing Future Faculty Program and has also received three Teaching Assistant Awards. She is also extensively involved in activities centered on diversity, equity, and inclusion, and has received awards to recognize these efforts, such as the Outstanding Collegiate Member Award from the Society of Women Engineers. Prior to UMN, she received her bachelor's degree in Chemical Engineering and her master’s degree in Materials Science and Engineering from Drexel University.

Moumita Dasgupta, PhD

Moumita Dasgupta (she/her) is an Assistant Professor of Physics at Augsburg University. Prior to this appointment, she was a Lecturer in the Department of Physics at Smith College and a teaching fellow at Amherst College. Her research interest falls in the experimental soft matter physics domain - at the intersection of biophysics, solid mechanics, fluid dynamics and materials. She is particularly interested in studying motion of active systems and their motility induced emergent behavior. Moumita is also involved in projects which uses an analytical and problem solving approach to conduct data-driven research geared towards solving civic challenges at the intersection of public health and development. She is passionate about undergraduate teaching and adapts a combination of traditional pedagogical styles like active learning, project-based learning, and design thinking methodologies. She cares about creating an inclusive learning environment in the classroom, where individuals of diverse socio-economic background, outlook, and culture feel equally welcome to participate and contribute.

Appendix A: Activity Sheet

Stage Design: Force Body Diagrams and the Normal Force

Materials for each group:

- Metal track with adjustable height on one side
- Angle detector (protractor)
- Digital Scale
- Two masses: 100 g and 500 g

Imagine that you're a stage designer and you're trying to determine how much force your raked stage can withstand. Use the following experiment to estimate the change in measured force depending on the angle of the stage.

1. Place the electronic scale securely on the track (match the rubber feet to the grooves in the track) and place the 100 g mass on it. Record the mass in the table below (angle = 0).

2. Tilt the track such that the angle detector reads 10 degrees. Record the new mass readout.

3. Tilt the track to 10, 15, and 20 degrees and record the new mass readout in the table at the end of the worksheet for each tilt angle.

4. Calculate the theoretical mass of the 100 g weight using the following equation:
   Calculated mass = m_0*cos(angle)
   where m_0 is the recorded mass when the angle is 0 degrees. Make sure that you are calculating the cosine in degrees and not in radians!

5. Calculate the difference in the recorded and the calculated mass by subtracting one from the other. How different are the recorded mass and the calculated mass? If they are different, what could explain the difference?

6. Repeat steps 1 - 5 with the 500 g weight. How different are the recorded mass and the calculated mass? If they are different, what could explain the difference?

100 g Mass			
Angle	Recorded Mass (g)	Calculated Mass (g)	Difference in Mass (g)
0	m_0 =		
10	m_{10} =		
15	m_{15} =		
20	m_{20} =		

500 g Mass			
Angle	Recorded Mass (g)	Calculated Mass (g)	Difference in Mass (g)
0	m_0 =		
10	m_{10} =		
15	m_{15} =		
20	m_{20} =		

– – PAUSE HERE FOR LECTURE PART TWO – –

7. Draw a force body diagram of the 100 g (0.1 kg) mass on the 15 degree inclined plane. Clearly label the normal force (F_N), the force of gravity (F_g), and the force of friction (F_f). Use the following table to calculate each of the forces. Assume the friction coefficient (μ) is equal to 0.3.

F_g = Mass * 9.8 m/s^2	N
$F_N = F_g$ * cos(angle)	N
$F_f = \mu * F_N$	N

8. (Not related to problem 7): As a stage designer, you need to choose the right stage material that can handle the weight of your performers. You want a stage that has a 5 degree incline. The cheapest material available to you can only withstand 5,000 N of force. Assuming your dancers weigh around 60 kg (60,000 g) on average, how many performers can safely stand on your stage? Be sure to show your work.

9. Consider the ethical and design implications of a raked stage. What is the largest tilt angle you would design? Why did you choose this angle?