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Case study on engineering design intervention in physics laboratories

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Approximately a quarter of undergraduate students enroll as a STEM major at some point during their undergraduate education, only half of those students leave having completed a STEM degree [1], [2]. Many factors can impact students' persistence in their major, however factors such as interest, career, and personal relevance, and grades in introductory courses are strong predictors of persistence within STEM majors [3] - [5]. Those who persist as a STEM major often find themselves underprepared for problem-solving within authentic settings.

Introductory STEM courses present engineering students with well-structured problems with single-path solutions that do not prepare students with the problem-solving skills they will need to solve complex problems within authentic engineering contexts. When presented with complex problems in authentic contexts, engineering students find it difficult to transfer the scientific knowledge learned in their STEM courses to solve integrated and ill-structured problems. The report by the President’s Council of Advisors on Science and Technology [2] emphasizes the need for developing important 21st Century workplace skills. One of the major recommendations from the *Next Generation Science Standards* [6] along with the Technology and Engineering Literacy Framework [7] is that integrating science courses with engineering design facilitates students' learning of scientific and engineering practices

The incorporation of engineering design in science classrooms also enables students to realize the relevance of science to everyday problems [8] – [11]. By integrating physics laboratories with engineering design problems, students are taught to apply physics principles to solve ill-structured and complex engineering problems. The integration of engineering design processes to physics labs is meant to help students transfer physics learning to engineering problems, as well as to transfer the design skills learned in their engineering courses to the physics lab.

The purpose of this case study was to examine how, and to what extent, students engaged in a physics laboratory that is integrated using an engineering design project engage in transfer. We begin by briefly reviewing the existing literature on the integration of science and engineering practices, then provide a brief overview of transfer. We then describe the context and content of the integrated physics labs, before presenting the case-study methodology used to examine two teams of students engaged in the labs.

STEM Integration

Integrating engineering design activities in physics have been shown to be effective in improving student achievement and attitudes [12] – [14], motivation, interest, and self-efficacy [15], [16], as well as learning [14], [17], satisfaction, and retention in STEM [18], [19]. Integration of design and science can also facilitate students to engage in metacognitive thinking [20] including the processes of planning, monitoring, and assessing their own learning [9]. This is particularly true when the design activities contain problems that require different problem-solving processes [21].

In addition to facilitating learning and metacognition, engaging in design has been found to improve students’ attitudes about learning. Engaging in design activities makes learners more responsible for their own learning and helps them buy into the notion that learning is a process of knowledge construction [22], which includes being creative, thinking critically [23], and internalizing their own knowledge [24]. It also cements the notion that knowledge itself is the product of design [25]. By helping learners realize the importance of attending to relevant features of a problem and activating the appropriate prior knowledge, engaging in design prepares to make students better prepared for future learning opportunities that may arise [26], [27].

The integration of engineering design activities into an undergraduate introductory physics course clearly has the potential to facilitate learning and transfer, particularly as physics is a word often associated with engineering [28]. However, there have been few attempts to integrate engineering design into undergraduate physics courses. Most undergraduate courses do not integrate science and engineering design practices, and few interventions integrate engineering design for the purpose of learning science or mathematics [29]. Typically, engineering majors learn engineering design practices in their first-year engineering courses, however, this learning is not addressed in the science or mathematics courses. The disconnect between the topics covered in their first-year engineering courses and their science courses may limit students' ability to transfer knowledge to other disciplines, leading to inert learning, and the inability to see the relevance of scientific principles to the practices of engineering design.

One instance of science and design integration in undergraduate education comes from Etkina and colleagues [30] who used the *ISLE* (Investigative Science Learning Environment) curriculum [31] - a curriculum that actively engages students in scientific practices. Etkina and colleagues [30] found that students who experienced design activities as part of the *ISLE* labs were more able to reflect on assumptions in procedures, communicated better, and were able to engage with new tasks in more "scientifically productive ways" than those who did not experience the design activities. In other words, the use of design in an undergraduate science context demonstrates potential to facilitate the transfer of scientific practices from physics to other sciences.

Transfer

Introductory STEM courses typically engage students in solving well-structured problems that provide students with all the needed information in one paragraph or less, and rarely include any unnecessary or irrelevant information. These problems typically have simple answers that are often only solved using a single path. In contrast, engineering design problems - such as the authentic problems that students will face after graduation - are often ill-structured, require integrating knowledge from multiple domains, and have multiple possible solutions that necessitate reaching consensus [32]. As such, when presented with complex problems in authentic contexts, students find it difficult to access and spontaneously transfer the relevant scientific knowledge to effectively solve these types of integrated and ill-structured problems [33] – [36].

Much has been written about what facilitates and hinders transfer [37]. What makes transfer unpredictable is the ways in which an individual perceives a problem in relation to previous problems will determine the extent to which individuals will transfer learning in one context to problems in another context. Those with keen insight may see a problem in a new context to be closely related to their learning, however others may be unable to perceive the similarity, and relevant learning is not applied to the new context [38] – [40]. Therefore, in this case study we examine the extent to which incorporating engineering design problems into physics labs will facilitate student making connections between engineering and physics concepts. In addition, we examine the extent to which students make connections between different physics concepts.

Description of Labs

First-year engineering students typically enroll in the calculus-based mechanics course at Purdue University, which is taught in a traditional lecture-laboratory-recitation format. This course has an annual enrollment of about 2400 students, about 80-90% of which are engineering majors. The engineering students are also typically enrolled in a first-year engineering design course either concurrently or during the semester prior. The physics course for engineers uses the Matter and Interactions [41] curriculum which focuses on first principle reasoning, iterative predictions, systems thinking, and modeling. The focus of the physics curriculum aligns well with course outcomes of the engineering design course to create a unified engineering design experience for these students spanning multiple courses.

Engineering design has been referred to as a “defining characteristic” of engineering [13]. It is a process that is problem-based, product-driven, and includes problem scoping, idea generation, project realization, and optimization [42]. The integrated physics labs were developed to include essential features of engineering design tasks. Namely, the design challenges presented to students were client driven, goal oriented, situated in authentic contexts, required students to create an artifact, and were team driven [43].

The physics labs integrated two engineering design challenges, each of which covered five weeks (see Figure 1). The first and last lab of each design challenge focused on developing and refining a solution for the design challenge. In these labs, students were also asked to reflect on the physics principles that were relevant to the design challenge and discuss how they applied in their design. The second, third, and fourth labs focused on gathering data, scientific inquiry, making connections to physics concepts taught in lecture, and computational modeling in vPython. This case study focused on the second design challenge of the semester. Students were presented with a client memo that asked the teams to address the problem of delivering supplemental food packages to a group of gorillas, who are an endangered species and live on an island in the middle of a large river. The teams were also presented with several constraints. First, the students could not disrupt the habitat, nor could humans interact with the gorillas. Second, the solutions needed to be environmentally friendly, including limiting noise pollution.

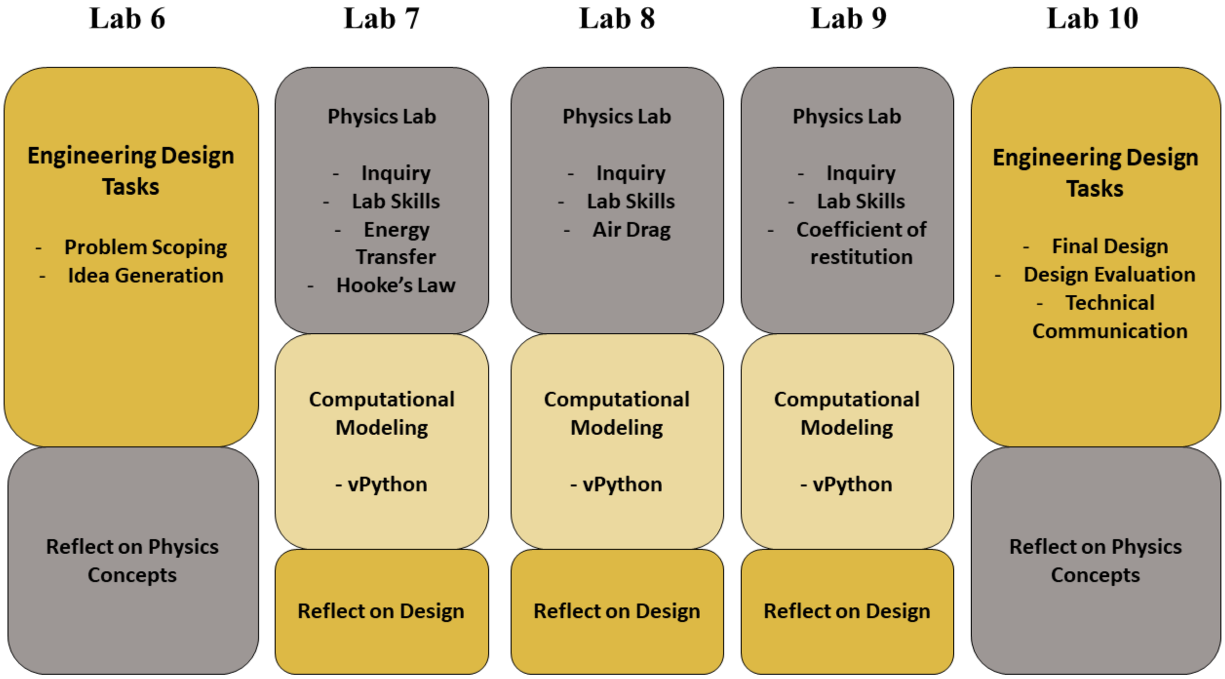

Figure 1: Overall Structure of the Engineering Design Challenges. This study examined the second design challenge, thus the first lab of the design challenge occurred in week 6.

Due to the design of the engineering design challenges, we anticipated that some questions would engage students in deeper and more creative thinking and would be more likely to facilitate transfer than others. We categorized the questions from the five labs into the following types: **Engineering Design questions, Conceptual physics questions, and Transfer-Stimulating questions** (Figure 2). Engineering Design questions explicitly ask students to engage in one part of the engineering design process. For example, students were prompted to identify stakeholders or asked to identify the constraints. Conceptual physics questions prompted students to calculate values, interpret graphs, derive or define things related to the conceptual understanding of physics. For example, finding the total energy of a system, or identifying the terminal speed of cups. Finally, transfer stimulating questions prompted students to explicitly form connections between the physics concepts and the engineering design challenge. For example, at the end of the labs in weeks 2-4, students were asked to reflect upon how that day's lab activity contributed to their understanding of the engineering design challenge.

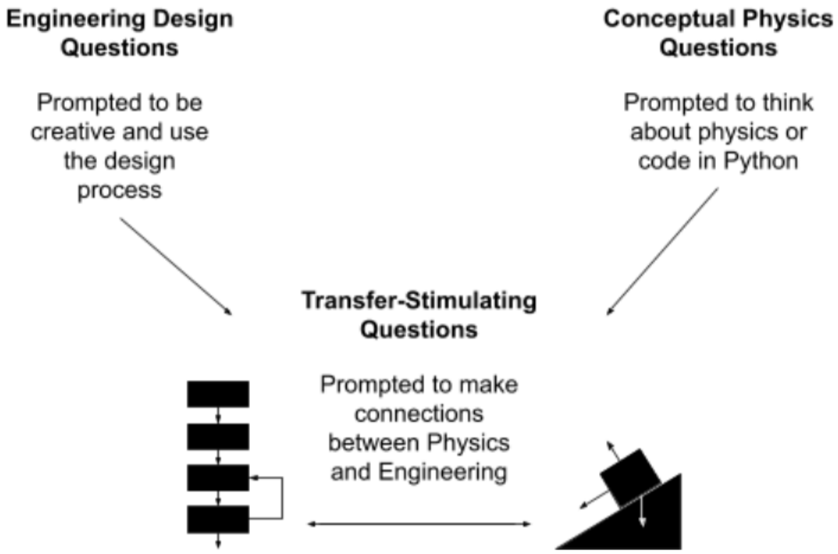

Figure 2: Representation of how Transfer-Stimulating questions allow students to connect physics and engineering

Methods

The cases presented in this study were selected using observations from the lab instructors of the team's work in the first design project. Two teams, one that performed well, and one that performed poorly, were selected to be observed to provide insight on how students use physics concepts to engage in the design process. We observed teams over the course of five labs as they completed the second design challenge.

Team 1 was composed of one female and two male students. Based on their conversations, they notably came from diverse backgrounds. They engaged in rich discussions, employed good team communication skills, and developed a great support system to complement each other's learning. Team 2 was composed of three male students. This team engaged less in conversations than the other team. Both teams completed the lab reports and engaged in rich discussion in the audio recordings. Team 1 structured what they were going to say before recording, while the second team engaged in much more natural conversation in the recordings.

Data Sources

Observations. Participant observation is a qualitative research method that allows researchers to get data on naturally occurring behaviors in context (Family Health International, et al., 2005). Although it is a time-consuming process to gather this type of data, this proved to be the most appropriate method for our research questions. Field notes allow the researcher to annotate things like non-verbal communication dynamics, feelings, and moods. This proved especially useful for observing the contexts that coincided with moments of co-regulation and transfer. Moments of metacognition and transfer when students worked on the integrated physics laboratories were captured by the researcher by means of field notes.

The researcher who observed the lab sections (first author) aimed to be as discreet as possible given that their presence can influence the ways that teams interacted with the design challenge. The researcher pretended to look at several tables at once while taking notes for only one or two of the tables. The students did not appear to attend to the researcher's presence and continued to perform prompted activities and engaged in natural communication. As such, the observations appear to capture interactions consistent with all teams.

Audio Recordings. In the modern world, it is easier than ever to find a device that can capture an audio recording. We can find recording devices on smartphones, cameras, webcams, etc. This accessibility allows researchers to gather data that would have otherwise been difficult to capture in real-time. In the labs, teams were asked to use their phones to record their discussions of engineering design reflections (labs 7-9) or physics reflections (labs 6, 10). This allowed us to capture their natural conversations as they engaged in connecting their design to the physics concepts learned in each lab. These recordings helped us identify **stimulated moments of transfer between the concepts**. Stimulated transfer proved useful to help students to transfer between engineering and physics concepts. While the participant observation allowed us to capture richer interactions between students when completing the laboratories, the audio recordings allowed us to capture unique moments of co-regulation that the other data collection methods could not capture.

Lab Reports. Laboratory reports are a deliverable of students' learning during a laboratory experience. Students were expected to work collaboratively to complete the laboratory report. Laboratory reports can serve as a guide, motivation for the students, form of assessment and data for research. The laboratory reports from the teams served to confirm that they were thinking about engineering and physics and jotting that down. If the students did not engage much in conversation, the laboratory reports served to capture moments of transfer between engineering and physics concepts or between different physics concepts.

Results

The purpose of this case study was to examine how, and to what extent, students engaged in a physics laboratory that is integrated using an engineering design project engage in transfer. Lab 6 sets the foundation for the second engineering design challenge. Students document their preliminary ideas in Lab 6, reflect on the impact of the physics concepts in labs 7-9, and revisit the design ideas in Lab 10. When students demonstrate that they have learned or clarified a concept, they undergo a moment of aha. This aha moment can be demonstrated in many ways, and as researchers, we use the data sources described above to capture these moments. Many times, these aha moments were instances where the teams demonstrated transfer of knowledge from one context to another. We also see a progression in the depth of transfer from surface level integration to a deep integration of physics and engineering practices. In the results section we explore some of these moments that occurred in each lab.

Lab 6. During laboratory 6, students familiarize themselves with Engineering Design Challenge #2. In summary, the Cross River gorillas in the Congo River basin are becoming increasingly rare and are an endangered species. Each team of students are told that they are engineers volunteering for a non-profit organization and are asked to design a system that can launch a payload of food to an island. The load must land safely for the gorillas. Weight and distance specifications are given and constraints such as minimizing the environmental carbon footprint, and neither humans nor a robotic machine must disturb the flora and fauna of the habitat while delivering the food.

Students engage in problem scoping by identifying stakeholders, criteria, constraints, assumptions, and any approximations that are needed. They decompose the problem by identifying the main functions and sub-functions that the design must include. Lastly, students brainstorm solutions by coming up with multiple ways to potentially solve the problem, then weigh the pros and cons of each. While there were no new physics concepts presented in this lab, the context of the design challenge facilitated students making connections between the design task and statistical thinking. For example, students in team 1 repeatedly used the term "chance of success" when engaging in their pros and cons analysis.

By using this term, the students demonstrated an awareness that whatever solution they came up with was not going to be successful every time. In this way they were engaging in probabilistic thinking. As an engineer, it is important to recognize that design tasks inherently have an acceptable error range. This is a concept that is discussed in the first-year engineering courses and not typically covered in physics. This indicates that the students likely transferred prior knowledge from a different context to the physics context.

In this lab, students were explicitly prompted to identify the physics concepts and principles that were associated with each design idea. While this was thought to be a potential prompt that facilitated transfer, the data indicate that little integration of physics occurred during the ideation stage of the design process. Rather than using physics principles to help design a food delivery system, the teams' discussions generally focused on design ideas, as well as the criteria and constraints. Any discussion of physics concepts was either focused on surface features (i.e., simply saying the terms momentum, or buoyancy) or delayed until after the design ideas were finalized.

Lab 7. During laboratory 7, students engage in inquiry by examining the motion of a mass on a spring, examine the energy transformations from graphs produced during the lab, and explore what would happen if the mass were launched by the spring through modeling in vPython. Students are then asked to reflect on how the inquiry lab and computational modeling are related to the design challenge. There was little discussion of the design challenge during the inquiry lab or the computational modeling task. However, explicitly asking students to make connections between the lab and the engineering design facilitated discussions of how the physics concepts could be transferred to the design. For example, during the team discussion one of the students in team 2 reflects on how they might be able to use ideas from the lab in the design challenge.

> *"Like having a simpler like strategy makes it way easier to model, like mathematically, because like we could just use like simple kinematic equations and like energy equations to model everything that we would have to do for this one."*

This quote indicates that the student is thinking about how they could use kinematic and energy equations to model the delivery of the food package in the design challenge in a similar way that they modeled the mass and spring in the computational modeling task in vPython.

Similarly, team 1 makes a connection between the inquiry component of the lab and the design challenge.

> Person 2: "So it seems like shooting the food out of some oscillatory motion cannon of sorts might be a good way if we can calibrate the amount of spring force this [lab] teaches us a lot about how spring force is connected to position and length."
>
> *Person 3: "And for the design challenges for this ... If the spring constant is too strong then it will destroy the food when it's launched and also the angle that the food is launched is also important because if the angle is too high, then when the food lands, the food may get destroyed. And also, the container that contains the food also needs to be designed because designing a way to protect the food when it lands."*

Here the students think about possible scenarios regarding the new physics concept and the safety of the food. They think about an imperfect load being launched that could possibly break or get damaged. In traditional physics, the load is usually a box and students do not relate it to a real-world problem. This demonstrates that students are actively thinking about real-world constraints and physics concepts altogether.

Lab 8. During lab 8, students were introduced to the concept of air resistance, the drag force, and projectile motion in two dimensions. Teams engaged in an inquiry lab where they calculated the drag coefficient under different conditions, then modeled projectile motion under the drag force in two dimensions in vPython. Finally, the teams are again asked to reflect on how the inquiry lab and computational modeling are related to the design challenge. Similar to lab 7, there was little discussion of the design challenge during the inquiry lab or the computational modeling task. However, the explicit discussion prompt facilitated transfer between the physics labs and the design problem. For example, when discussing their design one of the students in team 2 said: *"Oh yeah, so the only thing that we would be changing is a cross sectional area. Yeah, so I guess we have to keep in mind keeping a smaller cross-sectional area to make it less damaging to the environment."*

Here the student not only demonstrates a connection between the lab and the design, but also that there are trade-offs in an authentic context which impact the physics of the design. In this context, the team needs to find a trade-off between increasing the drag force to slow the package, thus minimizing damage, and the environmental impact of a large parachute. Later in the discussion, the idea of trade-offs that impact the physics of the design is again raised by a student who says, *"Yeah, so I mean there has to be a balance of like the angle that you launch it at, but also has to be with enough force to be able to get the food to the monkeys."* The discussion then expands to incorporate the angle of launch, the physics concept from lab 7, and expands to include a discussion about the materials that could be used in the design.

> *Person 1: "Yeah, so some ways we may approach it after completing this lab are we could like think about different materials we use that would create more drag like more way, increasing velocity."*
>
> *Person 3: "Second, so our ideas changed greatly, whereas before we believed that a simple cannon would be enough to launch the food, we now realize that*

> *there are many aspects of force that are applied to the bananas and in order to transport the food carefully and efficiently from one location."*

Here the students extend the line of inquiry from the lab and discuss that the drag force could be related to the materials used in the parachute. The discussion considers velocity and momentum in how they relate to the safety of the food. Here students exhibited both, a moment of transfer as they were exhibiting a moment of metacognition. In addition to connections between physics concepts and the design problem, the teams were making connections between scientific inquiry, computational modeling, and engineering practice. This is evidenced in the discussion from one of the students in team 1.

> *"Also, this lab reminded me that the importance of simulation if we haven't done this lab and actually try it out and simulate it on vPython, we have not noticed that. It's definitely reminding me that as a future engineer learning how to do the vPython and actually simulating it out before the real-world experiment is very crucial to the success of the projects that we may work on in the future."*

Here the student makes an important connection between scientific and engineering practices. In both cases, computational modeling represents a powerful process that is critical to success in both scientific and engineering practices. Interestingly, this connection was unexpected as the labs were designed to facilitate transfer within the context of the design challenge. However, this quote demonstrates that the students are making connections between processes outside of the immediate context of the design challenge.

Lab 9. Laboratory 9 introduced students to the coefficient of restitution. Teams engaged in an inquiry lab where they calculated the drag coefficient under different conditions, then modeled a projectile that bounces in two dimensions in vPython. Finally, the teams reflected on how the inquiry lab and computational modeling were related to the design challenge. Again, there was little discussion of the design challenge during the inquiry lab or the computational modeling task. However, the explicit discussion prompt encouraged the teams to apply the ideas from the inquiry lab and computational modeling to the design challenge. For example, one of the students in team 1 discussed how to safely land the food payload to gorillas in the remote habitat, *"So that means now if we shoot bananas out of our cannon, we have to understand that there might be some loss of total energy and that we need to calibrate our device better to account."*

Here the student related the idea that a collision will result in a loss of energy to the payload containing the food in the design challenge. The fact that students made connections between collisions, energy conservation (or loss), and the design challenge demonstrates how students are actively thinking about physics concepts in their designs.

Lab 10. Lab 10 consisted of students revisiting the design challenge and making decisions about their final designs for the engineering design problem. The objective of this lab was for students to load a simple computational model of a parachute-payload delivery system in vPython. The teams are then asked to modify the code to safely deliver the payload. Finally, the teams revisited their design ideas, and selected a design as their final solution using the criteria, constraints, and their knowledge from the prior labs. Both teams elected to employ a spring-loaded launcher with a parachute system for their final design (see Figure 3). In contrast to lab 6, the teams engaged in an integrated discussion of the physics concepts and how they related to the design of their food delivery system. One example of the integration can be found in the discussion that team 1 engaged in as they worked on their computational model. The teammate who was working on the code begins the discussion by asking their team, “What are we saying about the spring constant?” Rather than simply using a calculated value for the spring constant, engage in an in-depth discussion about how changing the spring constant will impact their calculations for air drag when the package is launched, and the coefficient of restitution when the package impacts the ground. During this discussion the students iterate the code for their computational model. The team concludes their computational model and reflect on how the model aligns with the authentic context that they have been designing for.

> Person 2: “Greater spring constant allowed to reach a greater height” “Friction is negligible” “No external force is taken into account” **“These assumptions are valid to create an ideal… they do not accurately affect the true surroundings**”
> Person 1: “**This is not gonna work in the real world”**

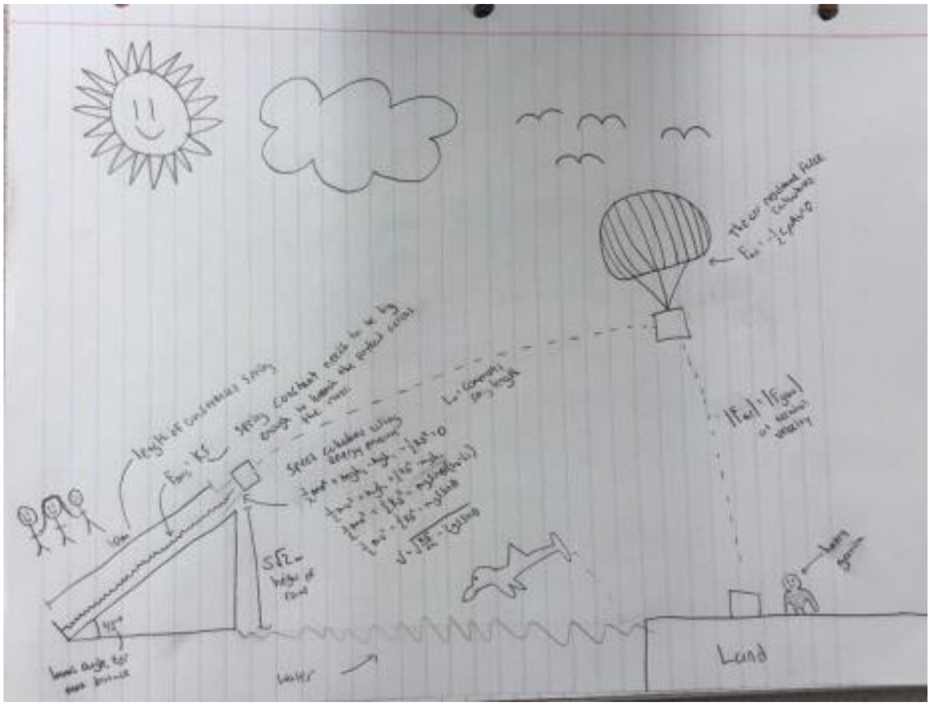

Figure 3: Sketch of the final design solution for team 2

Here we see the students engaging in transfer between labs as they connect the concepts of the spring constant, air drag, angle of launch, friction, and the coefficient of restitution into their computational model. They students reflect on how these concepts impact their design, and how the computational model is a simplification of the real context. The text highlighted above in bold represents a moment where the students became aware that the real world has even more complications than the ones they face in this engineering design challenge. This connection allows students to transfer the physics concepts into an authentic setting. By reflecting on how the ideal model may misrepresent the authentic context, the students begin to integrate physics concepts into their understanding of the design constraints of the challenge. Similarly, the students in team 2 also begin to integrate their understanding of the design challenge with concepts learned from the physics labs. As this team was working on their final design they engaged in a discussion where they examined the physics concepts at different stages of the package delivery in their design (Figure 3).

> *Person 1: Forces acting on payload, Wildlife, Weather conditions, Package reaches terminal velocity, and the velocity stays constant after the parachute is deployed.*
> *Person 1: Is there something more cost effective like a spring? If we do motorized, maintenance would be expensive. Just making the big spring is a big initial cost. It won't disrupt the environment too much.*
> *Person 2: The ramp can have an exit angle and it won't affect the environment as much.*

Person 1 began by discussing the forces acting on the package as it was launched and the parachute deployed, then the team worked backwards to the launching mechanism. As person 2 is discussing the exit angle, they use their hands to indicate a short, steep ramp. This exemplifies a common occurrence in lab 10, as the students would often use physical gestures to model a component of their design as they discussed physics concepts or design constraints. Here we see the students explicitly transferring the physics concepts from the labs to the specific pieces of their final design. We also see the students bringing in ideas, such as economic and environmental analyses, from their first-year engineering courses. The students think holistically, demonstrating connections from previous labs and other courses to the context of the design challenge.

Summary of Findings

Analysis of the team's interactions provides evidence that students successfully transferred the conceptual knowledge from the physics contexts to the engineering design process. Concepts that were introduced to students in their lectures appeared in the team's discussion of their food delivery design. Some of these were kinematic equations in Lab 7, launch angle and cross-sectional area in Lab 8, conservation of energy in Lab 9, and spoke holistically about physics concepts in Lab 10. The teams not only made connections to concepts learned in their physics course, but also used those ideas to drive aspects of the designs. Similarly, students drew on lessons from their other courses to propose solutions to the design challenge. For example, we see evidence of connections to probabilistic thinking in Lab 6, oscillatory motion in Lab 7, the utility of simulations in Lab 8, and economic/environmental analysis in Lab 10. This is an important finding, as the ability to make connections across disciplines is a skill expected from engineers in practice that is not often taught until senior capstone courses.

Conclusion and Discussion

From an educational standpoint, transfer is one of the most difficult things to design for as an instructor [44]. As prior research has shown, students are often unlikely to spontaneously engage in transfer between contexts [34], [37]. However, by situating physics students within an authentic design challenge, and explicitly designing the labs to motivate students to apply the physics concepts covered in the lab to the design challenge, students in both teams were able to engage in productive transfer. The design challenge situated the physics concepts within an authentic context, giving students a purpose for learning the physics, and a context for applying the concepts to solving an engineering problem.

Looking across the five labs, we note a progression in the depth of integration of physics concepts and engineering design. In lab 6, the connections between the physics and the design were minimal and focused on naming physics concepts that might apply to the design. The physics concepts were discussed at a surface level and were not integral to any design decisions. Across labs 7-9, students reflected on the components of their solutions from lab 6 and began to integrate the physics concepts into the designs. The students also made connections to prior labs as they reflected on the design. Transfer happened all throughout the labs, however moments of transfer typically occurred in response to the transfer-stimulating questions. In other words, asking students to explicitly consider how the physics concepts explored in the inquiry labs, and computationally modeled in vPython, were related to, or impacted their engineering design was critical for facilitating integration and transfer. It is also important to note that these connections were always made during discussions of the design, meaning that the integration of the different physics concepts would be less likely to occur without the context of the design challenge.

Lab 10 was a critical component to closing the cycle on the second engineering design challenge. During this lab, the teams were highly engaged and actively discussed the physics concepts covered in labs 7-9 and reflected on how these concepts impacted their design decisions. The teams exhibited more energy, were more talkative, and had richer discussions during lab 10. The students appeared motivated by the engineering design context and engaged in productive reflection on the physics concepts covered in the labs. These findings are particularly promising given prior research that indicates that students do not spontaneously make connections between design tasks and scientific concepts (Crismond 2001; Nathan et al. 2013).

In addition to the integration of multiple physics concepts, and the transfer of those concepts to the context of the design, students transferred practices learned in their engineering courses to the design challenge. As noted above, the teams engaged in discussions of trade-offs and conducted economics and environmental analyses when finalizing their designs. The students also made connections between the practice of computational modeling to the processes of scientific inquiry and engineering design.

Limitations and Future Work

This study focused on the extent to which incorporating engineering design problems into physics labs facilitated transfer between engineering and physics concepts, and between different physics concepts through an in depth case study approach. This method allowed us to analyze how the context of the lab tasks impacted the ways in which students made connections between concepts and domains. While this study focused on two teams in great detail, the labs were implemented across all sections of the introductory physics labs. In addition to audio recordings, pre and post surveys, concept inventories, and metacognitive inventories were collected and will be analyzed in future studies to examine how the implementation of design activities impacted students' conceptual learning, metacognition, and course perceptions.

One limitation of this study was that audio recordings were only collected during moments when teams were discussing the transfer-stimulating questions. While the researcher observations captured the team interactions during the other components of the lab, this study design prevented us from fully analyzing the role of the different question types in facilitating transfer. Future studies will video record teams of students as they engage in all components of the lab to analyze the role of different question types in promoting transfer.

An additional limitation of this study was that because we were interested in identifying the extent to which the current integrated laboratory design promoted transfer, we did not examine a control group. While we hoped that by selecting teams that were identified as needing different levels of scaffolding in the first design challenge, we would be able to identify aspects of the labs that needed to be modified to scaffold for teams of different abilities. However, as noted above both teams were successful in all aspects of the integrated labs.

Acknowledgements

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