Board 45: Physics Innovation and Entrepreneurship (PIE) Introduced into the First-year Physics Course

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ABSTRACT:

The J-TUPP, Phys21 report reminds us that most physics bachelor graduates are employed outside academia and that important skills for these students include a creative ability to apply physics knowledge to real-world settings. We are introducing students to the ideas of innovation and entrepreneurship as a way to enhance their entrepreneurial mindset and to encourage them to think about applying their physics knowledge throughout their 4-year physics program. In this presentation we report on how we introduce these ideas into a typical first-year course, taken by all physics, computer science, and engineering majors, without sacrificing a large proportion of course time.

We have used the Hyperloop, a high-speed transport system proposed by a joint team from Tesla and SpaceX, to have students investigate technical feasibility and human desirability questions that can be addressed throughout their first semester course. With each new physics topic, we are able to present a design question related to the Hyperloop that requires students to apply their just-acquired knowledge to the question and then to brainstorm implications and possible solutions guided by design thinking principles.

As a first example, we ask what maximum acceleration would be acceptable to passengers on a train and investigate how much time is added to a trip from Boston to Washington, DC if the Hyperloop is to make several stops along the way. Since the Hyperloop is expected to reach a maximum speed of 760 mph, a significant amount of time must be spent speeding up and slowing down and, in fact, if the Hyperloop were to make 6 stops, it would probably not even be able to reach its maximum speed. This leads students to discuss novel ideas for getting passengers on and off the train without requiring it to slow down and ideas for keeping passengers comfortable with higher accelerations.

Introduction:

This paper focuses on introducing a unit in the introductory physics course as an example of a Physics Innovation and Entrepreneurship (PIE) education module. This approach can be considered to be an activity-based learning session using a problem-based approach that highlights the relevance of introductory physics courses that can enhance students' engagement and interest in physics [1-3]. We have briefly introduced a Human Centered Design approach, or Design Thinking, to show the connection between physics knowledge and societal impact when technical feasibility is explored using laws of physics, correlated with human desirability and financial viability of a technical solution. The approach boosts purposeful learning as compared with the typical textbook end-of-chapter physics problems.

Physics Innovation and Entrepreneurship (PIE) modules when developed to leverage design-thinking provide attention to human needs creatively and appropriately [4], in contrast to presenting physics topics in a manner that students perceive to be uninspiring or not relevant to real-world applications. The design thinking approach in recent years has found its way from traditional design fields to a variety of non-traditional settings, including the design of courses and curricula. This includes the development of a toolkit by IDEO, a leading design consultancy, that focuses on application of design thinking for educators in terms of course and curriculum reimagining using design thinking [5]. The use of the design thinking approach enables us to formulate physics problems in a context that reveals the purpose behind the application of physics knowledge, which may be attractive to all students, especially underrepresented minority students, considering how it connects Physics Innovation and Entrepreneurship (PIE) with the empathic and user-oriented aspects of a technical feasibility using physics knowledge [6]. The use of the design thinking approach, even if only a brief introduction in the context of teaching physics allows for enhanced learning using context analysis [7-9]. We recognize that in the absence of a sufficient body of work on presenting physics topics using design thinking, more work is needed to better understand how design thinking may be used in teaching physics concepts. The impact of such an approach also depends on the unique features of each physics course that may affect the use of design thinking in teaching various physics topics and applications. However, there is clear evidence that standard end-of-chapter homework problems are not effective in imparting these skills to students (see [10] and references sited therein).

Ultimately, this work is guided and shaped by three major Physics related initiatives; (I) Phys21 report that was developed by the Joint Taskforce for Undergraduate Physics Programs (J-TUPP), a collaborative effort involving AAPT and APS [11], (II) Physics Innovation and Entrepreneurship (PIE) that is a collaborative effort through the American Physical Society (APS) [12], and (III) the PIPELINE Network ; a collaborative effort involving the American Physical Society and several higher-education institutions [13].

Implementation:

The Hyperloop is a high-speed transport system proposed by a joint team from Tesla and SpaceX [14]. Most students have heard about the Hyperloop, as it and similar concepts have been much in the news [15]. We have developed end-of-chapter type problems, based on the Hyperloop that are beneficial pedagogically in helping students understand basic physics concepts, but also lead naturally to questions of design and human desirability.

Our first problem involves accelerated motion. We initially have a discussion about the maximum acceleration that would be acceptable to passengers and then have students investigate how much time is added to a trip from Boston to Washington, DC if the Hyperloop is to make several stops along the way. Since the Hyperloop is expected to reach a maximum speed of 760 mph, a significant amount of time must be spent speeding up and slowing down and, in fact, if the Hyperloop were to make 6 stops, it would not even be able to reach its maximum speed. This leads students to discuss novel ideas for getting passengers on and off the Hyperloop without requiring it to slow down. There have been concepts for conventional train developed that involve a "moving platform" consisting of a second train car running parallel to the main train at each station so that passengers could get on or off while the train continues at constant speed [16]. Our students came up with a novel solution of having a separate pod carrying passengers who are boarding the Hyperloop leave the station as the Hyperloop approaches so that it is up to speed and can join the Hyperloop at the front, while a pod at the end of the Hyperloop carrying passengers who wish to disembark breaks away as the Hyperloop approaches the station and slows to a stop at the station. All this can happen without the main Hyperloop slowing.

The second exercise involves a discussion of centripetal acceleration in the Hyperloop. We first have students estimate the radii of curvature necessary to get the Hyperloop to pass through various cities along its route (see map) and then calculate the centripetal accelerations associated with these paths. As these values are close to the speeding and slowing accelerations discussed in the initial exercise, this leads naturally to a discussion of the combined effects of the tangential and centripetal acceleration; a concept that is difficult for students to understand.

The third exercise involves an analysis of the forces that act on a passenger undergoing the tangential and centripetal accelerations discussed in the previous exercise. Recognition that accelerations along a person's vertical axis (as in an elevator) are more tolerable than horizontal accelerations, leads to a discussion of banking of a road surface and the idea of fictitious forces in an accelerated reference frame; concepts that students often have difficulty understanding. Our class came up with the novel idea of suspending seats from a pivot at the ceiling (with some damping to prevent oscillations) so that the seats would naturally align with the direction of the fictitious force.

Additional exercises include the power (and cost) associated with overcoming air resistance; for both traditional trains and the Hyperloop, and the necesity of having the Hyperloop move through a tunnel with reduced air density; issues with possible collisions involving Hyperloop trains (not pretty!); and even a discussion of the reduced aging of Hyperloop passengers due to time dilation effects (not much!).

There is a real advantage in having an example such as the Hyperloop as a theme throughout the semester [17]. We introduce these problems to students in a group problem-solving session each week and we had students coming to that class trying to guess what the Hyperloop problem would be about. This means that, presumably, they were thinking about the Hyperloop as they were reading about the week's concepts; exactly the kind of engagement we hope for.

We plan to do a more formal assessment of these ideas next fall after having completed this pilot run this year. We did receive a number of positive student comments about the Hyperloop problems such as:

> I loved the thought-provoking Hyperloop problems. Every day of physics is like solving a puzzle. I love it.
>
> I liked the Hyperloop questions. Kept me intrigued doing fun example problems.
>
> The instructor did a great job implementing real-world scenarios.
>
> Real-world examples are helpful to understand the content of the course.

There are other examples that can be used in ways similar to the Hyperloop. For example, we have built a series of problems and exercises around human-powered pumps that have been developed and subsequently used for irrigation in sub-Saharan farming communities [18]. In all these approaches students are introduced to open-ended questions and need to deal with the ambiguity that is an integral part of real-world problems. This allows for creativity and innovative problem-solving, beyond what can be achieved through the applications of equations only.

Summary and Conclusion:

To use physics courses to better prepare physics majors for various careers or to engage and excite all students taking introductory physics courses requires teaching physics that better connects with students. This does not mean that we need to abandon the rigorous technical education that is part of the physicist education. However, even in introductory physics courses there may be ample opportunities for preparing students for today's careers. Physics topics presented in the context of relevancy and social impact can better serve and are more likely to attract a more diverse set of students with a broader range of career interests.

Design of new physics modules such as the one presented here should consider elements that go beyond a rigorous physics and technical knowledge. For example, new modules in physics can include elements that can have an impact on broad consensus regarding needed skills, knowledge, and attitudes for students such as understanding how science and technology are used in real-world settings and understanding the context in which physics topics are introduced. According to the Phys21 report, physics majors should gain knowledge in four areas to be successful in the future which include; (I) Physics-specific knowledge, (II) Scientific and technical skills, (III) Communication skills, and (IV) Professional and workplace skills. The module introduced here goes beyond the physics-specific knowledge that traditionally is covered in physics courses by incorporating elements from scientific and technical skills, as well as professional skills using problem-based examples that requires understanding or awareness beyond traditional physics knowledge and emphasis on relevance and the relationship with various elements in addition to solid understanding of the laws of physics.

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