PHYSICS LAB REFORMATION

An Interactive Qualifying Project
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Abstract

This project is an investigation on the feasibility of a transition from the classic laboratory system in Introductory Physics to a skill-based project orientated laboratory. It will be looking into the various deficiencies of the current system and how can these be addressed by changing the overall format of the lab part of the course. Furthermore the research includes both already implemented ideas in different campuses across the country and theoretical suggestions made by physics faculty in assorted journals and conferences. The aim for this investigation is to provide a different type of learning outcomes and environment that has been the status quo for decades and attract more students to the subject of Physics.
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1. Introduction

A project orientated lab course falls into the culture of WPI which emphasizes the importance of project work. As the WPI Plan mentions “Projects are the heart of WPI’s curriculum… you’ll work with peers to create solutions to real-life problems”. Every student has to complete three major projects to graduate including two that are generally outside one’s major. This is very important as the school promotes learning with practice. This is where the classic format of the Physics lab can be improved in many ways to better align with the WPI plan.

In order to implement any new ideas on the lab course the physical constraints must be considered. The main question is whether there is the available space needed for such an endeavor. WPI enrollment is at an all-time high. This means that the introductory physics classes are expanding due to them being a requirement for most majors. It is estimated that during A-term of 2018 there will be over 600 students signed up for Introductory Mechanics. Even though the lab sections are more numerous than the lecture ones it can still be an obstacle. A sufficient space is therefore needed that will also have the necessary equipment for a project orientated lab course. Fortunately, opening at the same time, the Foisie Innovation Studio has a makerspace that may fulfill the requirements. These will be discussed later on in more detail but include certain elements such as rapid prototyping.

As mentioned earlier, one of the reasons this project was started was to make Physics more attractive and beneficial to students. As it is currently the enrollment of students in Physics programs across the USA is not following the same growth as the rest of the STEM programs [1]. There are many reasons for this but an important one is that physics can appear very
theoretical to the average student. This can create the idea that there aren’t any applications in places outside the academia and research for physicists. Of course this is a false narrative and we can show this to students who are mostly undecided about their career path. It all starts though, with introductory physics where the students can experience the real-world applications of physics by themselves. And since more than 600 students will be taking this course as their first college course it is important to give them the right impression about Physics.

The main debate about Physics laboratories is on what the central goal should be. During this project I will be examining the various aspects of each main goal. The four main goals as identified by the J-TUPP report are, theoretical knowledge, technical and scientific skills, communication skills (including the write-up of lab reports) and professional skills [1]. Ideally a laboratory course should cover all four of them but an emphasis on one of the four is expected.

Additionally I will be looking into the nature of the project. Certain questions that have to be answered are on the length of the project and whether it will be a full term project or will a more classic approach be followed building up knowledge to a final project towards the end of the term. The decision on this is affected by many factors including the faculty’s attitude towards a full term project for classes with a tremendous volume of students.

My proposals will largely revolve around the guidelines and suggestions of the J-TUPP report along with other research findings [1]-[3]. These are valuable resources as they have been conducted by people with experience in the field of Physics and teaching and they have been backed up in terms of resources. They will be adjusted to WPI’s specifications and even expanded on creatively to explore ways in which further innovation can be achieved.
Unfortunately this project will not have the time to implement its proposals and hence neither evaluate the results of said proposals. Therefore I will be looking at ways this can be done in the future. One of the tools I will be using to see what the faculty’s attitude is to such a change will be a questionnaire. This will not be limited to the physics faculty. It is very important to make sure that faculty in the rest of the departments would not be overwhelmingly opposed to such a change since their students make up the majority of the enrollment in introductory physics.
2. Literature Review

This section will evaluate the background to skill based laboratory courses as well as to lab courses where a project has been implemented or suggestions on how to implement such a change.

2.1 Theory based Labs

In many institutions Physics Labs are taught as part of a theory class and their objective is to strengthen the knowledge and improve understanding of the theoretical material learnt in class. Essentially the lab hours work as an extension of the lecture with a practical experiment. To measure whether this plays a significant role to a student’s theoretical knowledge and understanding an investigation was carried out by Holmes and Wieman to measure “lab benefit” [2].

In this survey they analyzed grades of students at three different institutions where the Physics Course being taught had an optional lab section. This allowed them to compare the exam performance of students who had taken the lab versus the students who had only taken the lecture part of the course. The courses selected for this survey were introductory physics that covered both Mechanics and Electromagnetism as well as Calculus and non-Calculus based learning. Both midterm and final exams were investigated. It was expected that a considerable performance difference would be expected in favor of the students who had taken the lab part of the course. This is justified by the additional 2 hours a week of exposure to the material the
students were being taught in lecture. The results though proved otherwise with the students who
had taken the lab doing at best 2% better than those who hadn’t and in some cases doing worse.

Another problem that arises from the guided theory-based labs is evident in an E-CLASS
performed by the University of Colorado Boulder where students actually came out of the course
with worse perceptions about laboratory procedures than they had when they started [4]. This is
mainly due to the nature of a guided course where the students do not have to think about the
experimentation procedures and/or the lab equipment they end up using. Therefore knowledge of
such concepts is considered unimportant by most students. This creates an unprofessional
mindset especially for Physics graduates who end up working in less theoretical fields. This is
especially harmful since most Physics Bachelor graduates end up working in the private sector
(61%) where 70% of them work at a STEM related job [1].

Lastly it would seem that students are not intellectually challenged by these labs [2], [5]. As the
study proved students are mostly concerned with finishing up in time and they do not care to
think of why the procedure was done or why was one equation used instead of the other. This
means that the labs offer very little to the student when it comes to theoretical knowledge even if
that was their goal. As Professor Douglas Bonn suggests, in order for labs to teach theoretical
knowledge would take far more time than other methods such as a lecture or a problem session
It would not be impossible rather ineffective. Therefore the lab’s aims have to change to a more skill-based approach or else the resources put into it are essentially wasted.

### 2.2 Skills and Goals

So if supporting the theoretical knowledge from the lecture is not an effective lab goal, the alternatives should be looked at. As mentioned earlier the majority of Physics graduates move on to the private sector with most of them employed in a STEM related job. This industry has certain demands from its employees as far as skills and knowledge. A few important to note are working well in groups, analyzing, designing and implementing a solution to a problem, plan and organization applying science in the real world and communicating clearly. It would be unfair to say that an introductory physics lab should be able to teach a student all these but an attempt to at least introduce the student to these concepts can be made.

According to the J-TUPP Physics students mainly learn professional skills that are fitted for the academic career and not the industry [1]. Skills such as problem solving and working with others are couple that can be used in both environments, but they are not really emphasized at the introductory level labs. Since the students are given everything they have to do in the instructions they are not engaging in problem solving. This also prohibits them from actually working with others. Even if the lab is performed in pairs when everything is laid out for them, students often just take turns doing the experiments and completing the lab questions. Their ability to work with others is not put to test since they do not engage in decision making.

Another important set of skills often overlooked are the Scientific and Technical skills. As mentioned earlier, by the end of a course, students do not believe they have to know how to operate the lab equipment in order to complete the labs [2]. Meanwhile their most prevalent
concern does not have to do with how the experiment was done but whether or not their data is reasonable. Expanding the students’ scientific skills requires the labs to be designed so that the students has to ask certain questions like what do they want to measure and how are they going to do it. Additionally students might be asked to suggest any other methods that could have helped solve the problem. If time allows they could try both methods and see which one is more accurate and/or consistent. The most practical way that this can be done is for the lab to be centered about a real-world case study. This will also make students feel that the skills and knowledge learned is applicable to the real world, something that is often not the case in early courses. This will make Physics a more desirable degree pursuit since the practical application of it is more obvious.

Finally there are the Communication Skills. Unfortunately the physics lab reports at WPI do not require much of the student as far as communication skills go. Most of the lab reports are in the form of fill in the blanks or have questions to be answered with a couple of sentences. Although this is convenient since there are many students, there is no cultivation of the communication skills in the written or oral form. The only exception to this is the PH1111 labs that require the student to write a lab report.
3. Methodology

This project has the following goals:

- To analyze students’ and faculty’s attitude towards a change to the Intro Physics Lab.
- To investigate and suggest possible alternatives to the current Intro Physics Lab.

3.1 Analyzing Attitudes towards a Change to the Intro Physics Lab

As it was mentioned earlier one of the most important parts of the project was to analyze faculty’s and students’ attitudes towards such an important change in the Lab curriculum. To accomplish such a task, a series of surveys were designed aimed at Physics Faculty and WPI students. This is important as Intro Physics classes are amongst the most popular courses at the school and therefore a large portion of students will be affected by these changes. Additionally this provides the survey with more subjects that can participate in it and hence a more inclusive and accurate result. On the other hand it was decided that only Physics Faculty will be subjected to a survey since Physics faculty will be directly responsible for any changes and other departments will minimally affected by it.

3.1.1 Faculty Survey

The two surveys were designed with the above in mind. For the survey directed to the faculty the questions are focused on the feasibility of any change as well as how beneficial they believe it to be for the students. It is important that these changes are not made just for the sake of moving towards a project oriented lab but to reinforce the student experience, make physics more attractive to students who are undecided on their major and also enhance the learning that the lab provides. As suggested by professors N. Holmes and Carl Wieman [2], the lab should be about teaching students to make their own hypothesis and develop certain skills that will help
them later whether this will be in an engineering environment or a more theoretical research career. This will be broken down in a few different questions that will look more into specifics of these skills and what can be changed about the lab to accommodate the new learning goals.

3.1.2 Student Survey

The survey directed towards the student has less about the learning goals and skills that are beneficial and more about the experience of the student during the lab. It is often the case that many students have a negative attitude towards the lab as something that is both boring and non-beneficial and this is what this project wants to change. It is often the case that a course might not stimulate the students’ interest in the subject if it is not engaging enough. By changing the lab so that the students are not given a strict set of instructions to be followed but rather a problem that they have to solve could lead to a more enjoyable and beneficial experience. The survey is aimed at students that have taken the Intro Physics courses. Questions will be asked on whether the students found the course beneficial and if their experience influenced them on taking more or less physics courses. Finally the students’ attitude towards a project-based lab will be analyzed using a series of questions regarding projects.

3.2 Investigating possible alternatives to the current Intro Physics Lab

For this part, as mentioned in the introduction, ideas for change will be drawn from literature and systems being implemented in other institutions and the responses from the surveys. A balance has to be found between these sources since there has never been such an implementation at WPI before.

Based on research [2], [5] have begun to move away from a theory strengthening session to a scientific and technical skills approach. More specifically the labs will concentrate on teaching
students how to come up with their own hypothesis and how to test it by experiment. Additionally, the results have to be compared with the theory via meaningful discussions and improvements suggested to the method being implemented to better test the hypothesis.

Furthermore, technical skills can be incorporated such as how the instrumentation impacts the designed experiment. This is because the students should learn how to extract the desired data from the readings in order to then analyze them.

Since this project is looking at the feasibility of the change rather than the actual changes that will take place and since the surveys cover the acceptability part, the two questions that remain are how these changes can be implemented and whether or not they will be practical to do so. The two main options that will be looked at are the skills based labs but within a traditional setting and a project infused lab section that is focused on skill learning. To answer those questions about the two options interviews have been conducted with professors and the lab manager and assistants.
4. Results and Discussion

In this section the results of the survey will be analyzed and the implications of these results will be discussed. Apart from the multiple choice section of the survey the comments will be looked upon and have that compared with the multiple choice answers.

4.1 Faculty Survey Results

Eleven members of the Physics Faculty responded to the survey. This puts the percentage above 50% which is a very satisfactory result. All of the faculty who responded have taught either PH1110/1111 and/or PH1120/1121. A quarter of the responses were from faculty that have been teaching for less than 5 years while the rest of them were spread out evenly among the different intervals given in the survey.

As it was expected most of the faculty think that the laboratory section is important or extremely important while very few think that it is not. If it were the other way then it would have been important to look into why that was the case. Since we know that the laboratory part is valued by most professors we can take a better look into the different aspects of the labs.

![Figure 2 Faculty Survey, Question3: On a scale from 1 to 5, 1 being “not at all” and 5 being “extremely” how important do you think the laboratory section of the Introductory Physics is?](image)
One of the most important factors that needed to be determined was the learning goals that the labs should have. This was split into the four main learning goals as described earlier in the report. Contrary to what the labs currently emphasize, which is improving the understanding of the theory learned in class, it seems that most professors think it’s more important for the labs to teach technical skills as well as process skills. As evident in the graph below only about 50% of the faculty would rate the reinforcement of theory as the important or extremely important while more than three quarters think that this is true for the technical and process skills. On this note something that should be added is that from comments received by the TA’s running the labs, it would seem that occasionally the lab schedule and the lecture schedule are not matched appropriately. This might be for various reasons such as snow days or a slower pace lecture section. This leads to the students not having the knowledge to complete certain labs due to their nature of being theory reinforcement sessions. Moving away from this to a more process and technical orientation would partly solve this issue as the lab would be more about how to collect data and what processes must be observed while doing so.

*Figure 3 Faculty Survey, Question 4: On a scale from 1 to 5, 1 being “not at all” and 5 being “extremely”, how important are the following goals for the Intro Physics lab?*
This is further emphasized on the next two questions where the faculty was asked about which type of lab they think is more beneficial for the students and which one would be easier to apply. Not a single response was in favor of the traditional labs in the first question. What seems to be the most popular opinion is that the labs should be a combination of a traditional setting with scientific skills being emphasized and with a possible small project being implemented at the end of the term. As one of the written responses said “Traditional labs could be revised to emphasize technical and process skills. Project-based labs for hundreds of students just does not seem practical”. This was an issue from the beginning of this project. While other classes in WPI would at most include 100 students, the Intro Mechanics course has around 600 since is a class needed for most majors.

It is clear then that including a full term lab project would be highly impractical since the resources both material and staff are unavailable. It is though possible for a project in the form of an extended lab report to exist. This would help improve communication skills as well,
something that the professors believe is an important learning goal. To this end it is possible for a project to be included as part of the lab. This in itself would be significant since it is already something seen in other undergraduate courses where a small duration project is included in the course.

![Figure 5 Faculty Survey, Question 6: In your opinion, what would be easier to apply?](image)

Finally one of the points mentioned in the introduction and the literature review was the nature of the instructions and more specifically how directed should they be. As noted earlier it is important for the instructions to leave some room for the student to think about what they are doing instead of blindly following a set of instructions. In this case the opinions seem to be evenly spread with about 40% of the professors believing it should be semi-directed and another third supporting fully directed labs. This has to do with convenience and organization since as one comment indicated developing the methods would take time. Again it would be beneficial to include the opinion of a TA supervising the lab section who said that it would be educational for the student to work out certain parameters themselves such as how many times should a measurement be repeated for more accurate results to be achieved but it would make the class
smoother if the students were guided to that idea. One of the comments from the professors indicated that as well, saying that the early labs should be more structured so that the students develop these scientific skills that they can use in later labs which can be more open-ended.

Concluding it seems that there is the desire for change from the professors’ side and more or less it follows what research has proven to be more effective. Unfortunately some of the more extreme changes such as a full term project lab seem unachievable. There is also some split of opinion regarding Entrepreneurial Mindset Learning which essentially is the application of entrepreneurial ideas in physics courses. This is ideal for improving the professional skills of students. Although most faculty think it is beneficial or could be beneficial, half of them think it is important and the rest don’t. Ideally it would teach an important set of skills but it might be more appropriate in a higher level course with less students where a bigger project could be implemented.

Figure 6 Faculty Survey, Question 7: How directed, do you think, should the lab be in terms of instructions?
4.2 Student Survey Results

It would seem that the major concern that students have with the labs is in regards to the instructions that are currently in place. This is evident as most of their comments as well as comments from the TA’s mention that the instructions are unclear and often leave the students confused on what to do. Around 40% of the physics majors responded to the survey for a total of 35 which gives us a satisfactory sample.

The first two questions are about their experience with Intro Labs and whether or not the labs provided any learning benefit. There is a clear dissatisfaction with the current labs and it is evident that they are in need of a drastic change. Only 16% of the students would rate their experience with Intro labs as good with over 50% regarding it as poor. This reflects badly on the major since this is the first exposure students have with Physics and it might discourage undecided majors.

![Figure 7 Student Survey, Question 3: How would you rate your experience, with 1 being “very poor” and 5 being “excellent”, with Intro Physics Labs?](image)

It is not much better when it comes to the next question which is about how much the students believe they learned during the labs. About 60% believe that they learned little to nothing. This is
in line with the results of the research that has been done and mentioned earlier regarding the lab learning benefit [2]. The labs clearly are of no benefit in their current state. Additionally one of the problems mentioned was that the lab work is disproportionate compared to what it counts for in the final grade. This has to be addressed in either decreasing the amount of work needed to be done for the labs or increase the percentage it accounts for in the final grade.

The effect it has on students’ perception of physics is further emphasized by the fact that most of the students would have probably not taken another physics course if they were not a physics major. More than 60% answered No when asked if the reason they took a course was because the labs sparked their interest in Physics.

Finally students were asked on whether they believed a change to a more project oriented lab would have made the experience better and if it would have increased the amount they learned from it. Most of the students were unsure whether it would have resulted in a better experience.
with their number being close to 50%. It is possible that there is a distrust towards the labs in general as one student responded in another question with the comment “Whichever as long as the instructions are less confusing.”

On the other hand students seem to be more optimistic on whether they would have learned more if a project orientate lab was to be implemented. Again though there is no strong conviction from the students’ behalf on the matter.
Concluding the students were asked about the lab procedure. A third answered that they would prefer the procedure to be less directed while another third said that they like the way it currently is with every step indicated. The rest responded with other. The comments of those that selected other include a combination of both but mainly they ask for a less confusing set of instructions. This seems to be the current issue that students have with the Physics Intro labs. A change towards a more scientific skills-based labs might help due to the removal of the more theoretical-heavy questions that currently exist. Also it would seem that the labs should be tried out before they are included in the course. This can be done in various ways but one suggestion would be to have a group of Physics students both undergraduates and graduates take the lab as a simulation and see if they think that the instructions are clear and the objectives are well-laid-out.
5. Conclusion

Although the lab for the Introductory Physics courses cannot transition to a full term project, many changes can be made to its current structure. Both from literature and faculty opinion the lab should transition to skill-based from its current structure of theory-based. This could be both technical skills and process skills but from a practicality point of view it makes more sense for a technical skills lab to be implemented. It is possible for the lab to have a project at the end of the term with more open-ended lab instructions to allow for creativity and problem solving thinking.

The main emphasis though of the change should be on making the instructions more clear and concise since this is what a lot of the students struggle with. As aforementioned the change to a more skill-based lab would by itself help but a simulation should be ran beforehand. This change is viable and desirable form both faculty and students. Since it does not require a lot of changes to the current equipment or TA system there should be no financial issues that affect the implementation. Dana Parsons who is the new Physics Lab Manager has already started designing the new labs based around scientific-skills learning so the process of change is underway.
6. References


