Microtechnology: The Project-based Approach

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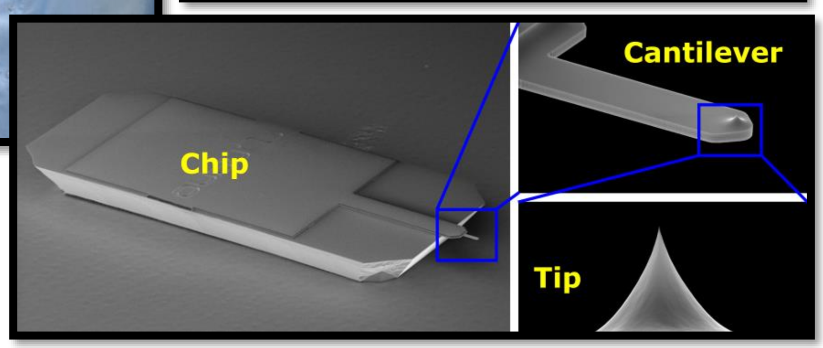

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October 13, 2021

[1] https://www.nunano.com/blog/2016/12/12/a-pedants-christmas-guide-to-afm-probe-terminology
[2] https://www.labmate-online.com/news/microscopy-and-microtechniques/4/oxford-instruments-xrf-libs-and-oes/new-high-quality-budget-priced-afm-probes-introduced-nbsp/42956

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Abstract

In the first two years of undergraduate classes, the Eastern Switzerland University of Applied Sciences (OST) is lecture-based, and projects are only introduced in the final two years. Our sponsor, OST professor Tobias Lamprecht, wanted to change this. The goal of this project is to develop a project-based learning module that will assist the OST to enhance its students' learning experience and improve their understanding of the material. We interviewed students and professors at both WPI and OST to gather data that helped develop the PBL module. In the PBL module, OST students will be given a rubric to guide research, manufacturing, and creation of their own atomic force microscopy probes. We hope that this project will open the door to new learning experiences for students at the OST.

Acknowledgements

We would like to thank our advisors Professors Francesca Bernardi and Nancy Burnham for their wonderful help throughout the past semester. They have provided us with valuable feedback that was necessary for our success with this project.

Professor Carol Stimmel—our ID2050 professor—is also someone we would like to thank. She taught us all the valuable social research principles that we used throughout this research project.

We also wish to thank all the professors that we interviewed about project-based education and microtechnology: Dr. Yarkin Doroz, Dr. Don Gelosh, Dr. Gregory Lewin, Dr. Rudra Kafle, Dr. Martin Gutsche, and Dr. Samuel Huber-Lindenburger. We would not have been able to complete our project without their gracious help along the way.

We are also grateful for all the WPI and OST students who completed our surveys and provided us with insight into project-based learning and the difficulties of microtechnology.

Lastly, we would love to thank our sponsor—OST professor Dr. Tobias Lamprecht—for coming forth with this project. He also provided us with a wonderful in-depth tour of the OST Buchs campus and the clean room. We had a great time working with him and enjoyed this amazing experience.

Executive Summary

The Problem

Science, Technology, Engineering, and Math (STEM) education are some of the most important fields in modern academia. The Eastern Switzerland University of Applied Sciences (Ostschweizer Fachhochschule, OST) includes Systems Engineering as one of its majors. Currently, students learn most of the material from lecture courses in their first two years, then they implement their knowledge in the last two years through more lab-based courses. Our sponsor—Dr. Tobias Lamprecht, a professor of microtechnology at OST—wants to integrate projects into the foundational courses offered at OST. This is known as project-based learning (PBL). OST currently does not have any usage of PBL within their systems engineering curriculum; all their projects are completed within lab courses which are separate from lectures. Seeing that Worcester Polytechnic Institute (WPI) is project-based, Dr. Lamprecht was hoping for our input as students to help him develop a module that would integrate a project into his course.

Project Goal

Recruiters and companies tend to look for skills such as teamwork experience and effective communication—which are developed in the project-based learning curriculum—and OST's job as a higher-level institution is to help prepare their students as much as possible for the work force. Our goal was to introduce a project-based module into a foundational microtechnology course at OST.

Objectives

Our first objective on the path to our project goal was to develop a foundational understanding of project-based learning. We as a group needed to better understand why PBL is a powerful method of teaching. Examples of courses that use PBL and their respective projects showed us the benefits of project-based education. Being able to see how instructors create their project-based educational plans, aided us in obtaining a greater understanding of the possible implementations of PBL.

After gaining a deeper understanding of project-based learning, the next objective was to determine what topics in Dr. Lamprecht's class syllabus met the qualifications to be turned into a PBL module. These qualifications were collected during our research and are as follows: early within the course, relatively simple to understand, and contained theories applicable in the industry. We chose atomic force microscopy (AFM) probes for the topic. This was because they are taught early in the curriculum, are a topic that is easy enough to learn on one's own and are highly used in the industry.

We created the project-based learning module that would be implemented into Dr. Lamprecht's course along with instructions for Dr. Lamprecht to implement the PBL module and monitor its success. We also produced several deliverables to act as steppingstones to a PBL-rich learning environment for Dr. Lamprecht.

Methods

Our first step in the data gathering process was to interview five WPI professors individually to inquire about their experience with projects, focusing on what worked and what did not work for them. To conclude our WPI interviews, we met with Professor Francesca Bernardi who was educated in her home country of Italy. Through this conversation, we were able to gain knowledge from a primary source on the differences between American and European higher education. Following this, we interviewed two

professors from OST. Their interviews gave us context into the culture at the University and a better understanding of how to best design our PBL module, along with the potential differences in American and Swiss higher education systems.

We delivered a survey to WPI students with the hope of gathering their thoughts on how class projects were received. The students surveyed were all involved in various engineering disciplines, although a special focus was put on contacting those in the robotics engineering program, which is known for having a high percentage of projects within their courses. Following this, we sent out a survey to roughly fifteen of Dr. Lamprecht's current and past students to inquire into what they felt were the hardest topics to grasp in his microtechnology curriculum.

Results

Objective 1: Developing a Foundational Understanding of Project-Based Learning

We sent out surveys to WPI students to gain a better understanding of how PBL has affected their education and helped them learn the course material. When asked to rate the quality of PBL based on their education experience, WPI students rated it on average 7.85 out of ten—as shown in *Figure* 1. This highlights that WPI students value project-based learning. Additionally, we asked WPI students whether they felt PBL affected how well they learned their class material; in *Figure 2* the average response to this question was 4.07 out of five, which underlines how PBL can help students learn more efficiently. After looking at this data, we became convinced that PBL would help better OST students' education. The next step in fully understanding PBL was interviewing professors on their experiences with developing PBL modules. These interviews helped guide our thought process as we investigated how to best cater to the OST students' needs.

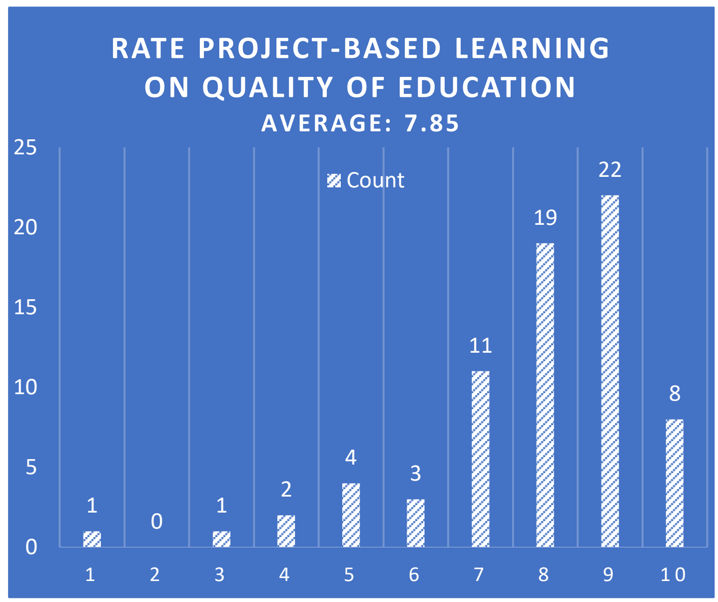

Figure 1: WPI students' rating on how project-based learning improved the quality of their education.

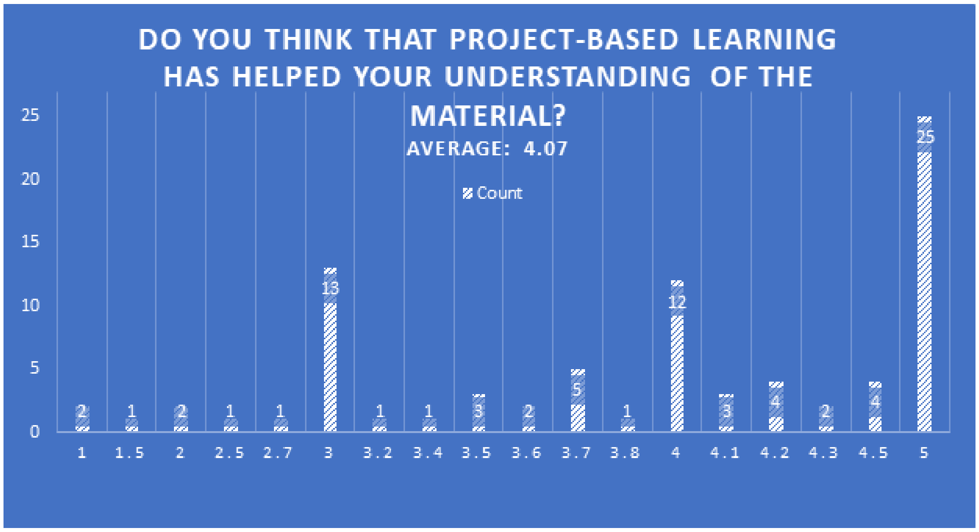

Figure 2: WPI students' rating on how project-based learning enhanced their understanding of course materials.

Objective 2: Selecting the microtechnology Topic

Choosing the microtechnology topic on which to focus our PBL module was done in stages. During our interviews with WPI professors we gained insight into what topics met our standards for PBL: early in the course, relatively easy to understand, and relevant to the industry. Next, we looked at the OST students' surveys to see what topics they were interested in having turned into projects or what they needed more help understanding. We ultimately selected AFM probes as our topic for the module.

The next step was understanding how certain topics taught within microtechnology are more suited to PBL. OST Professor Gutsche discussed how using the clean room is a key aspect of microtechnology. When we visited the OST campus, Dr. Lamprecht gave us a tour of the clean room. It took several minutes to change into clothes for the clean room as it is a highly controlled environment where the amount of dust must be kept to a minimum. Consequently, it would be quite difficult and costly to have students working there every day. This reinforced the idea that it would be burdensome to have our PBL module take place within the clean room, as our sponsor previously explained.

The final step in the topic selection process consisted of combining what we learned from the interviews and surveys so that we could work with Dr. Lamprecht to pick the topic. Dr. Lamprecht gave us a list of topics to research and narrow down. We made sure the chosen topic was a relatively simpler subject within microtechnology to ensure the students were less overwhelmed in this initial project experience. All this analysis led us to AFM probes, which are widely used in microtechnology to help map the topography of a material.

Objective 3: Creation of the Project-Based Module

Once we gathered additional information on AFM probes, we began developing the final deliverables. This final project will be an enlarged model of their assigned AFM probe (yet still only a millimeter in length). The students will be split into groups of three, each assigned with their own unique probe type to research and build. The OST students will be asked to create two presentations, a preliminary design review (PDR) and a critical design review (CDR). The main goal of the PDR is to give Dr. Lamprecht the opportunity to check in with groups and help steer them back on track if they are strafing from the project goals. The PDR can be seen almost as a halfway check-in with the project. The CDR will be the final presentation for the project and will build off the PDR.

One of the most important deliverables for Dr. Lamprecht was our grading rubric. In our discussions with Dr. Lamprecht, we decided to use a ranked scale for the sections on our rubric. Students' performance will be evaluated as follows: presentation skills, content, knowledge of topic, and the final model. The public speaking section of the rubric will be weighted less than others for one main reason: the students do not have much experience in being graded on their public speaking. The content portion of the rubric will be weighted the most since this is the most important information that Dr. Lamprecht wants his students to retain from this project.

Table 1: List of three deliverables that are provided to our sponsor, Dr. Tobias Lamprecht, alongside this report.

Deliverables:	
Project Rubric	A rubric for Dr. Lamprecht to grade his students' projects on
Project Timeline	A timeline for when to assign certain parts of the project
Post-Project Student Survey	A survey that Dr. Lamprecht will distribute to his students after completing the project to gauge their interest and its impact

To gauge the success of this project-based module, Dr. Lamprecht will need a way to see if the students benefited from its integration into his class. We must turn to the students and obtain their feedback. We provided Dr. Lamprecht with a sample survey to administer to his students after the module has been completed. This survey would allow Dr. Lamprecht to see if his students benefitted from the implementation of the AFM probe project. These deliverables will be crucial to the successful implementation of the PBL module within Dr. Lamprecht's course.

Conclusions and Recommendations

Our end goal in creating this project was to deepen students' understanding of microtechnology topics, improve their CORE skills, and better prepare them for the workforce. We interviewed professors and surveyed students to gain a better understanding of how to complete this goal. Several professors stressed that starting with the end in mind is the best approach to creating any project. We used this advice to develop the guidelines for our PBL module.

For any future IQP projects related to creating a PBL module, we recommend interviewing a variety of professors at WPI to gain insight into their experiences. The quality of information gathered from these interviews would be more consistent if the professors operated in a field related to the project topic. Additionally, when creating any PBL modules, it is important to keep student opinions in mind. Ultimately, the module is for the students and keeping their interests in mind is imperative to the success of a module. We hope that in several years, OST will have project-based learning in every course, just as it is here at WPI.

Authorship

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Objective 3: • **Purpose** • **Data Sources**	• MacGregor • Petrie • Simpson	All

• **Data Analysis** • **Research Limitations**		
Conclusion	• Petrie	All
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Conclusions & Recommendations	• Petrie	MacGregor

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1 Introduction

Science, Technology, Engineering, and Math (STEM) education are some of the most important fields in modern academia. Without STEM, the skills required for technological advancements would be hindered. Students, researchers, and those who are employed in the field of STEM drive advancement and innovation within the disciplines. Therefore, it is important to focus on motivating students to continue to engage in the fields of STEM, which will help society reach those achievements. Currently, most STEM classes are lecture based. These lectures require students to memorize graphs, equations, and theories which can be hard to remember. Since STEM-based jobs are rapidly changing, the way they are taught also needs to be changed. A university in Switzerland is wanting to start making these changes.

The Eastern Switzerland University of Applied Sciences (OST, the Swiss name of the University) in Buchs, Switzerland specializes in systems engineering. Currently, first and second year students learn most of the material through lecture courses. These lectures are taught in the traditional format in which students sit, listen, and take notes for one-to-two hours. There are rarely any interactive components. It is only in their third year that they begin to receive practical training through lab-based courses that involve some projects. This is unlike Worcester Polytechnic Institute (WPI), where their courses are taught with projects in almost every course. Luckily, they are not alone in the interest in projects. There are professors at OST that want to incorporate projects into those first two years of education. One specific professor was so interested that he connected with WPI and became our project sponsor.

Our project sponsor, Dr. Tobias Lamprecht, is a professor of microtechnology at OST. Dr. Lamprecht wanted to integrate projects into the first- and second-year courses at OST. The integration of projects into courses is called project-based learning (PBL). Dr. Lamprecht wanted to use PBL to help his students develop stronger familiarity with the processes behind topics such as microtechnology and photonics. Additionally, this would also allow students to gain more hands-on experiences that can be applied to their careers. In later years at the university, students have opportunities to participate in projects within their courses. Our sponsor felt that by not having projects earlier in their college careers this created a gap at OST that needed to be filled with PBL.

The Eastern Switzerland University of Applied Sciences has a clear line between their lab and lecture courses, with little-to-no overlap. OST is a technologically advanced university where they utilize state-of-the-art equipment; that allows them to perform complicated experiments that many schools do not offer. Their choice to focus on traditional lecturing limits how much hands-on learning is applied in the curriculum. The lab courses that are taught in the third and fourth year of the systems engineering curriculum are the only courses that integrate projects. By integrating projects earlier, students can gain more experience with building class related PBL projects and experiments.

Recruiters and companies look for skills such as teamwork experience and effective communication—which are developed in the project-based learning curriculum—and OST's job as a higher-level institution is to help prepare their students as much as possible for the work force. Our goal was to help OST establish an understanding of how important it is to implement PBL into their lecture courses. The first step in this process was to define what PBL is and how it works in different class environments. Next, we needed to understand microtechnology, the topic Professor Lamprecht teaches in his courses. Microtechnology is a broad topic with a variety of different applications and subsections. Finally, we developed the module itself. This module took an existing topic in Professor Lamprecht's syllabus and format it to fit a PBL module. By the end of the module, we wanted students to develop a deeper understanding of microtechnology, improve their teamwork skills, and develop better competence organizational relational effectiveness (CORE) skills for the workforce.

The project-based learning module that we created will help the Eastern Switzerland University of Applied Sciences integrate a hands-on curriculum into their systems engineering department. The module focused on microtechnology and its real-world applications, aiming to express why project-based learning is worth OST's investment. We plan to show that when implemented well, project-based education is a highly efficient teaching style for microtechnology and other engineering disciplines.

2 Background

In a world infused with technology, the need for smaller, faster, and more efficient circuits is growing at a rapid rate. The path to these advancements lies within microtechnology. Microtechnology refers to electrical components measuring approximately one micrometer in size. They can be used to make phones, cars, and even medical devices smaller, smarter, and more efficient. This field can be advanced more efficiently by increasing the interest in learning about microtechnology and better educating any future microtechnology professionals. One way to increase interest and allow students to develop project skills with microtechnology is to apply a hands-on approach. Our project focuses on using a hands-on teaching style to help students become more involved with STEM. Project-based learning is a teaching method that emphasizes teamwork, problem solving, and critical thinking. The overall goal of this project is to create a clear pathway to expand project-based learning into the field of STEM education, with a focus in microtechnology.

2.1 Project-Based Learning

2.1.1 Definition of and Reasoning for Project-Based Learning

Project-based learning (PBL) incorporates an active application of skills and knowledge to an activity or project. PBL is used as a catalyst to further engage students in their topic of choice. To set up a project-based curriculum, one should start with a problem that needs to be solved, then research, build, and present (Johnson et al., 2019). People applying for jobs often only focus on honing their technical skills listed on job requirements by potential employers. However, interpersonal and communication skills are an often-overlooked requirement (Johnson et al., 2019). Project-based learning can help build those skills. Real life applications of skills such as leadership, collaboration, communication, and problem-solving skills are all strengthened by PBL and better equip students for success with employers than the traditional school learning environment (Johnson et al., 2019).

PBL is an example of successful collaborative teamwork-based learning, versus the traditional passive style of learning. Since 2007, PBL has been used at the University of Aveiro, Portugal, among many other places. Data collected from the students by Margarida Pinho-Lopes and Joaquim Macedo indicate that the collaborative model has better a retention of engagement, team building, and academic performance (Pinho-Lopes & Macedo, 2016). Through trial and error of finding more effective ways to help students retain information presented in the classroom, the hands-on project style of PBL holds students accountable for their own academic performance while giving them more leverage, allowing them to choose how to tackle their project.

2.1.2 Previous Applications of Project-Based Learning

Looking at project-based learning from a textbook standpoint, it appears to be ideal for students and teachers. Students develop their own projects, form solutions themselves, and develop solid problem-solving and interpersonal skills along the way. Teachers get to engage students in topics they are passionate about, reduce their out-of-class preparation time, and get new outcomes with each new class of students and projects. The next natural step is to explore studies on the practical applications of this theory.

For instance, a study published in 2008 detailed an experiment in two middle schools in the Detroit Public Schools district, where certain sections of seventh and eighth grade students were switched to a project-based curriculum in their science classes. This was done during a time when the Detroit system was trying to improve their overall education quality for several different reasons: below-average standardized testing results, lackluster engagement, poor attendance, and a struggle to retain highly qualified teachers (Geier et al., 2008). While Detroit has historically poorer academic success compared to much of the United States, tackling all four points of desired improvement resonated with many teachers and professors. After about 1.5 years of this new learning style, researchers analyzed the students' performance on the state standardized testing and found that while scores among formula-based questions remained the same, performance in questions that required problem-solving and critical thinking was substantially improved. As shown in Figure 1, this led to a 19% increase in passing rate in the first school, and a 14% increase in passing rate in the second school. Remarkably, the study authors also found that the change in teaching style greatly reduced the gender gap in results among urban African American boys who had been falling noticeably behind the girls in their classes within these Detroit Schools (Geier et al., 2008).

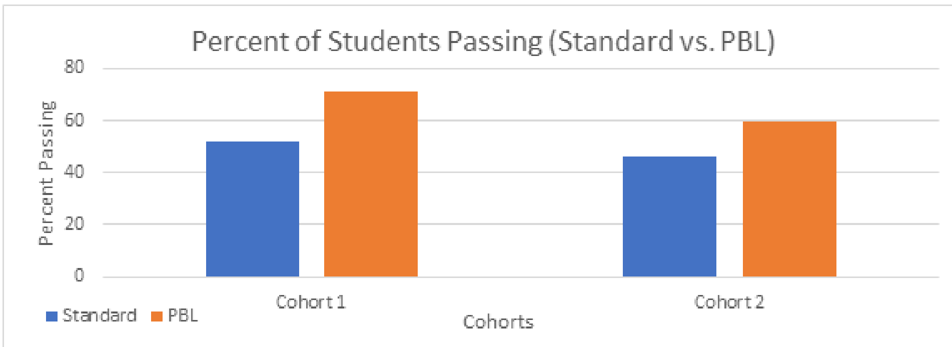

Figure 3: Percent of students passing Detroit standardized exams (Standard vs. PBL) (Proposal Author's interpretation of Geier et al., 2008).

Figure 1 also demonstrates just how significant the change in scores was following the integration of projects into these middle school science classes. However, it turns out project-based learning functions well beyond just middle schools, as shown by another study conducted in Chicago. This 2012 study analyzed students in a set of Biotechnology courses at Harold Washington College to see if project-based learning could show changes at a higher education level. The course was made up of students who were unfamiliar with the course content, with 16.7% not even knowing what biotechnology was. By the end of the course, 91.7% said they enjoyed the class enough to feel encouraged to enroll in similar coursework, with 100% of the students saying they would recommend this specific class to their peers (Movahedzadeh et al., 2012). The shift to a resounding 100% positive recommendation at the end from a group who in some cases had no basic understanding of the topic is encouraging. This study shows promise for students in PBL courses that are not exclusive to young age groups but apply across the board.

2.2 Microtechnology Studies

2.2.1 Introduction to Microtechnology Within Society

Microtechnology studies is the field of shrinking electronics and mechanical systems to make electronics more efficient, compact, and easier to manufacture. It is an ever-expanding field that has many real-world applications that are pervasive in modern society. By helping students better understand the concepts, we can better prepare them to contribute to the field in a more efficient manner; hence, advancing technological applications in society even further. But what is microtechnology? Oxford defines microfabrication as the creation of small electronics, down to about 1 micrometer in size – or about 1% the diameter of a human hair (Escudier & Atkins, 2019). As the societal demand for more powerful electronics increases exponentially, so does the demand for its size to decrease. In the mid-1940's, the first computer was produced – the Electronics Numerical Integrator and Computer (ENIAC) – it was 50 feet long and weighed-in at a whopping 30 tons (Stuart, 2018). Nowadays, we have wearable computers that weigh under a pound and can do more computations per second than what ENIAC could do in a day. These leaps and bounds are all thanks to the evolution of microtechnology.

The term microtechnology was coined in 1963, and its applications grow within our society more and more each day (*Definition of MICROTECHNOLOGY*, n.d.). Seventy-five years after the invention of the first digital computer, many of us might sit anywhere in our homes and be within arm's length from multiple computing devices. Microtechnology has a vast impact on our modern lives, it lives in everything from phones to televisions to automobiles. As microtechnology advances, more and more people have access to electronics. For example, in the year 2020, the average American household had over 10 'connected devices' [computers]. There is an increase of 20% of computers within households worldwide in the last 15 years (See *Figure 4).*

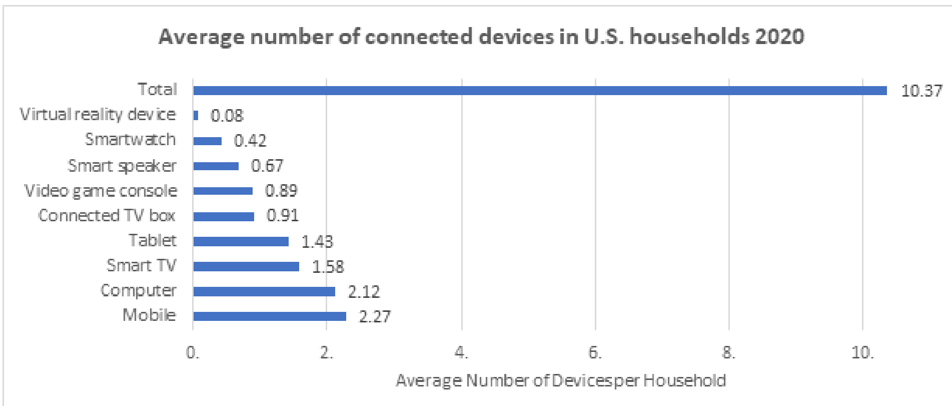

Figure 4: Average number of connected devices per household within the US in 2020 (Authors' Graph of Average Number of Connected Devices in U.S. 2020, n.d.).

With the growing integration of technology into homes, as seen in *Figure 4*, the demand for these products is also increasing. The growing reliance on computers within our society means that we also have a greater need for technology to be smaller, more powerful, and more efficient. Microtechnology is the answer as to how we are going to advance these electronics.

2.2.2 Applications of Microtechnology

The applications of microtechnology are found in a lot of places, but how are people currently applying it? There are many different types of microtechnology, and they all have their own unique purposes. Some notable applications are found in the medical field and in analysis of micro surfaces.

According to Prof. Dr. med Marc Schurr, the founder of Ovesco, the applications of microtechnology to the medical field are broken up into four components: extracorporeal devices, intracorporeal devices, implantable devices, and endoscopic diagnostic & interventional systems (Schurr, 2007).

There is a machine called an atomic force microscopy (AFM) probe; it is used to analyze surfaces with micro/nanostructured coatings and can obtain high-resolution nanoscale images (Aliofkhazraei & Ali, 2014). Each type of probe analyzes a different property of the material. Some examples are force modulating microscopy, electrostatic force microscopy, nanoindentation probes, and magnetic force microscopy probes.

2.2.2.1 Medical Microtechnology

Extracorporeal devices are used outside of the human body. These include, but are not limited to, mechanical organs, advanced prosthetics, and wearable electrocardiogram [ECG] monitors. Some mechanical organs currently used are lungs, livers, and kidneys (Schurr, 2007). The main purpose of these machines is to help the patient remove or move different bodily fluids from the needed organs (*Textiles for Extracorporeal Devices | Nonwovens & Technical Textiles | Features | The ITJ*, 2009). These external machines help many people function outside of a hospital setting and allow them to live normal lives.

Intracorporeal devices are made to be used in or deal with the inside of the human body. One of the most common applications of intracorporeal devices are AI-based surgical robots (Schurr, 2007). These robots use microtechnology to be the most precise and efficient at preforming surgery on humans. One of the more well-known surgical robots today is the da Vinci surgical system – which is an AI controlled surgical robot. Another form of an intracorporeal device is a ventricular assist device (VAD). This device helps the heart pump blood from the lower sections to the rest of your body (*Ventricular Assist Device (VAD) - Mayo Clinic*, n.d.). These devices are most often a temporary solution used to strengthen the heart but can become a more permanent implanted device.

Implantable devices are implanted during surgery and remain in the patient. Examples of implantable technology are heart peacemakers, artificial hips or other damaged joints, and implantable cardioverter defibrillators (ICDs) (24/7 Wall St., 2011). Most of these devices rely on microtechnology to be small enough to work with a human body and remain strong through years of use.

The final application of microtechnology in medical devices is endoscopic diagnostic and **interventional** systems. This technology is used to exam internal organs without the use of surgery. An endoscope must be long, flexible, and small; without microtechnology this would not be possible. “An endoscopy is often used to confirm a diagnosis when other devices, such as an MRI, X-ray, or CT scan are considered inappropriate” (“Diagnostic Endoscopy,” n.d.). Such procedures can help determine if someone has internal bleeding, stomach ulcers, or even a breathing disorder. The wide use of microtechnology in medical devices alone shows the versatility and relevance of this technology; with these qualities it has changed the way medical devices can help people (National Research Council, 2010). However, medicine is not the only application of microtechnology.

2.2.2.2 Using Microtechnology to Analyze

Force modulating microscopy (FMM) is a type of atomic force microscopy that is used to analyze materials to determine their mechanical properties (such as frictional coefficient, adhesion, and elasticity). “FMM uses a Contact Mode detection scheme to monitor changes in sample topography, while simultaneously applying a high frequency signal to the cantilever” (Force Modulation Microscopy (FMM), n.d.). A cantilever is a long beam with a point attached to the end; the end point is reflective in most cases so a laser can be used to read the data the cantilever collects as it moves across nano surfaces. FMM is primarily used for surfaces such as polymer bends and metal alloys as they typically have nonuniform properties.

Electrostatic force microscopy (EFM) is used to study electric fields on sample surfaces. It produces a map of the sample’s electric field that gives information about the surface’s charge and potential (Electrostatic Force Microscopy (EFM) - Nanosurf, n.d.). This information provides subjective information on the electric fields of the sample surface and shows the sample’s electrical properties. EFM works by using a cantilever that is coated with a thin electrically conductive material that is moved at a high frequency. This causes static electricity to form along the sample’s surface; when the probe moves along the surfaces the differing heights caused by the static electricity can then be analyzed by scientists.

Nanoindentation probes works by pressing the cantilever into a surface until it causes an indentation, and it then is moved across the surface; this is used to determine hardness, facture toughness, yield strength, or modulus of different materials. This process is faster and more efficient way to analyze materials regardless of size (“Mechanical Testing,” n.d.).

The final AFM probe example is **magnetic force microscopy**. This type of AFM helps scientists to comprehend how magnetic forces work at a nanometer scale. It creates a map of the magnetic force gradient that appears on the sample surface while also gathering topographical data – the data collected includes naturally occurring and constructed structures in the magnetic materials (Magnetic Force Microscopy (MFM), n.d.). This information can be used to help advance areas such as biology, biomedical, and biomaterials (Passeri et al., 2014).

2.3 Project Based Learning Within Microtechnology

The pedagogical style of a lecture has been around for hundreds of years. Most human inventions, such as the automobile, go through a few iterations in the span of a century. Similarly, the education system needs to be updated just as frequently. Education is the lifeblood of modern society; humans strive to learn more each day to better advance society, which is why education is so important. Project based learning is the new form of education that can benefit the fields of STEM. Microtechnology is a fundamental part of STEM, and its education would likely benefit from the incorporation of project-based learning into the curriculum. By applying project-based learning to STEM classes, students are provided the opportunity to have a hands-on, collaborative, and more realistic educational experience. The use of project-based learning in STEM allows students to obtain a more real-world experience that will help them in the long run. Project-based courses are a more efficient alternative to having both lab and lecture courses. Lecturing is a good form of education under certain conditions but implementing project-based modules into the classroom promises to enhance student understanding of the topics (see *figure 1*). The implementation of a project-based classroom is vital to the greater success of STEM students (Geier et al., 2008).

Project based learning is an increasingly sought-after technique to prepare students for their careers (Movahedzadeh et al., 2012). Microtechnology is a complex, multi-faceted subject that students often have trouble comprehending, this means that students often have trouble retaining the information given to them. Our sponsor, Dr. Lamprecht, shared with us that many of his students struggle with learning the concepts of microtechnology due to the sheer scale of the topic. He hoped that implementing project-based learning into the field of microtechnology will increase students’ understandings significantly (T. Lamprecht, personal communication, May 10, 2021).

As discussed previously, the passing percentage of middle-school students within a project-based learning environment is significantly higher than those of students in a traditional educational environment. Giving students the opportunity to learn in a project-based environment allows them to understand the material in a more meaningful way. Additionally, it helps prepare them to grapple with real world applications. The STEM field is very competitive, and students should be more prepared to go into the work force (T. Lamprecht, personal communication, May 10, 2021). STEM education is full of equations, graphs, and simulations, which are not always the easiest for students to understand. Therefore, the implementation of project-based learning is crucial to the advancement of STEM education (Movahedzadeh et al., 2012). Microtechnology would greatly benefit from the implementation of project-based learning.

2.4 Conclusion

In a world where technology is constantly evolving and advancing, an education in microtechnology is a fast-growing necessity with a wide range of professional opportunities. Our project focuses on creating a didactic learning module to have the students show an understanding of the functions of an atomic force microscopy probe. Students who benefit from hands-on experience can learn and apply knowledge more readily in a microtechnology specialty. Since microtechnology is a field that has a lot of nano-sized components, having visuals would improve understanding of the topic. PBL shows promise as a solution to the challenges of teaching this curriculum, given the complexity and minuscule components.

3 Methods

The goal of this project was to develop a project-based learning module that would assist the Eastern Switzerland University (OST) in enhancing its systems engineering students' learning experience and improve their understanding of the material. The first step in this process was to develop an understanding of important aspects of PBL curriculums. Next, we determined which topic students would benefit most from being transformed into a PBL module. Finally, we created the module and all its corresponding attachments (timeline of deliverables, syllabus, etc.). This process was developed like a funnel, starting from the broad topic of PBL and narrowing the process down until we had a specific method developed.

3.1 Objective 1: Developing a Foundational Understanding of Project-Based Learning

3.1.1 Purpose

Our first objective was developing a foundational understanding of PBL along with its applications and implementation. We as a group needed to better understand why PBL is a powerful method of teaching. Examples of courses that use PBL and their respective projects showed us the benefits of project-based education. Being able to see how instructors create their project-based educational formations aided us in obtaining a greater understanding of the implementation of PBL. Gathering a copious amount of data was crucial to our success in understanding PBL.

3.1.2 Data Collection

The data collection for this objective involved interviews and surveys with students and professors at WPI and OST. All questions we asked are listed in *Appendix A*. Our first step in the data gathering process was to meet with three to five WPI professors individually to inquire about their experience with projects, what worked, and what did not work for them. We selected professors from the Systems Engineering, Robotics Engineering, and Electrical and Computer Engineering departments because of the increased likelihood of them having directly worked with microtechnology-related subjects in their teaching and research. To conclude our WPI interviews, we met with Professor Francesca Bernardi who was educated in her home country of Italy through her master's degree before moving to the United States for her PhD. Through this conversation, we were able to gain knowledge from a primary source on the differences between American and European teaching and learning styles in higher education. Following this, we interviewed two professors from OST. This gave us context into the culture at the University and a better understanding of how to best design our PBL module, along with the potential differences in American and Swiss higher education systems.

Following those interviews, we delivered a survey to WPI students with the hope of learning their thoughts on how class projects (delivered in part by the above professors) were received. The students surveyed were all involved in various engineering disciplines, although a special focus was put on contacting those in the Robotics Engineering program, which is known for a high propensity of projects. Finally, we delivered a separate survey to Dr. Lamprecht's current and past students to gain a stronger understanding of their experiences with projects. All questions asked are listed in *Appendix A.*

Table 2: List of sources interviewed alongside the corresponding information-type gathered.

Sources of Information	Interview: PBL Experience	Interview: Academic Culture
WPI Robotics Professors	✓	
WPI Systems Engineering Professors	✓	
WPI Electrical Engineering Professors	✓	
OST Professors		✓
WPI Advisors	✓	✓

3.1.3 Data Analysis

After we collected the data, we organized all the information according to topic, type of data, and resource. The process for analyzing the interviews required several steps. First, we organized the notes according to what school the interviewee was associated with. Next, we separated each interviewee's responses and created a color-coded key for different topics we wanted to highlight – the key had different topics associated with different colors. After creating that key, we analyzed the notes from the interview. Finally, we compiled a list of any important sections we planned on referring to in our final report.

To gain a better understanding of PBL, we analyzed our survey results in both qualitative and quantitative manners. Quantitative results were turned into graphs that would easily depict the different questions (the graphs are highlighted in *section 10.1*). Each graph was focused on one question in the survey process. Qualitative results were analyzed and sorted into the categories listed above. This data will be presented through summaries in the results chapter of our paper.

3.1.4 Research Limitations

In our research we learned that, like all other teaching methods, project-based learning isn't a flawless teaching approach; there are several limitations to implementing it in classrooms. One major limitation is how students react to this change in learning style. Every student prefers a different style of learning, so it is difficult to meet every student's needs. Changing a course to be completely project based may be hard for inexperienced students to adjust to. This can be because if a student has not had any project experience, they may have issues working effectively in groups, putting them behind in the coursework. Another limitation was how few responses we got to our OST student survey. While we were only expecting three-to-five responses due to the small class sizes of Dr. Lamprecht's classes, it was still unfortunate to not be able to hear from more of his current and former students.

3.2 Objective 2: Developing the Microtechnology Topic

3.2.1 Purpose

After gaining a deeper understanding of project-based learning, the next objective was to determine what topics met the qualifications to be turned into a PBL module. We needed to gather information on all areas of a topic and analyze Dr. Lamprecht's class syllabus. For our project we were focusing on a subsection of microtechnology. To develop the topic, we analyzed what challenged the students the most, what part of the class structure could be made hands-on, and if the professor would prefer one big final project or a small project to go along with the lecture material. This questioning helped us narrow down what topic was possible for this project. We also took into consideration what the students would be interested in working on and what they would benefit from the most based on our data collection methods. Our survey responses helped us determine what would or would not engage students about PBL, to make this class project experience as beneficial as possible for them.

3.2.2 Data Collection

The majority of the data collection process involved direct collaboration with Dr. Tobias Lamprecht. First, we looked over Dr. Lamprecht's class syllabus to gain a better understanding of what was being taught. As we went through each section of the class, we asked him to point out three-to-five class topics that students have historically struggled with. Following this, we sent out a survey to ten-to-fifteen of Dr. Lamprecht's current and past students – hoping to receive responses from at least three-to-five students – to inquire into what they felt were the hardest topics to grasp (questions shown in *Appendix A*). Our online research, as described in the background section, gave us a solid understanding of the major applications of microtechnology, and therefore what students would need to understand the most. Finally, we cross-referenced all the data to determine which topic would benefit the most from being transformed into (or bolstered by) a PBL module.

Table 3: Type of information alongside the sources used to acquire said information.

Type of Information	Student: Surveys	Professors or Teachers: Closed Interviews	Online Sources/ Databases
Class Syllabus		✓	
Tough Topics	✓	✓	
Topics of Interest	✓	✓	✓

3.2.3 Data Analysis

After we collected our data about microtechnology topics through interviews and surveys, we analyzed the data to better understand them. During the interviews with the WPI and OST Professors, we took extensive notes and transcribed them following each meeting. After transcribing the notes, we used thematic code to find commonalities within the questions asked. We also color coordinated the themes and then sorted out the quotes and data, which made them easier to reference and analyze. We also questioned WPI professors on how they had created and sustained their project-based learning courses so we could better understand how they continue to successfully integrate PBL into their class. When we went through our thematically coded interviews, we began collecting the recurring methods for how professors create a PBL module. The PBL module will guide students into a deeper understanding of the topics taught in the course.

Our surveys gathering the student preferences in project-based learning, were administered to WPI students and included qualitative and quantitative data. This data was used in different formats. The qualitative data was used to gather quotes, information, and stories on how project-based learning had impacted their STEM education. The quantitative data was used to get a numerical representation on how often WPI students are exposed to PBL, and their appreciation of it. Our surveys for the students at OST gathered qualitative data. This data was used to obtain a better understanding of the typical types of education in Switzerland. We also obtained a better understanding as to what the students found more challenging with microtechnology. To better understand our qualitative data, we used thematic coding as well to find commonalities within the responses.

3.2.4 Research Limitations

During data collection, our most glaring limitation was students providing minimal information in their responses. Another limitation was the risk that any syllabus given would not fully encompass what would be taught in Dr. Lamprecht's class. That risk required us to utilize online databases to fill in any gaps. Creating a learning module was a new challenge for us; our own lack of experience was itself a limitation. Additionally, we did not have prior experience or knowledge about microtechnology. This lack of field-specific scientific knowledge limited the capability of what we could teach and replicate.

3.3 Objective 3: Creation of the Project-Based Module

3.3.1 Purpose

Following the completion of the methods outlined in Objective 2, we moved onto the development of the module. We chose a single topic for which we would design a project-based module for our sponsor. The module that we created focused on only one topic for three reasons. One, we only had a short period of time to design and create the physical module to give to Dr. Lamprecht. Two, by giving our sponsor only one topic to work on in PBL format, he has less to change in his course curriculum. Three, changing one topic's instruction to PBL will ensure that the students will slowly be introduced into the idea of project-based learning. So, the first point of action was establishing a topic for the module.

3.3.2 Topic Refinement

To ensure project success, we had to narrow down the topics of microtechnology that Dr. Lamprecht teaches and choose one that we felt would be a good candidate to be turned into a PBL module. We asked Dr. Lamprecht to provide feedback on the types of modules we offered him. It was vital that we included Dr. Lamprecht in the creation of this module so he can use our framework to develop his own projects in the future. We looked toward our OST student survey to get a better understanding of what topics they have trouble grasping. Our hope is that the module that we created will support the students in a topic that they tend to struggle with.

After informing Dr. Lamprecht on the basic concepts of PBL, we asked him to provide us with a list of microtechnology topics that he thought would be viable for a project-based learning module. Due to the reduced timeframe for our project, we decided to choose the topic that we felt we could understand the best from amongst the options provided.

3.3.3 Building the Project

After deciding upon the topic, we worked backwards and established a list of takeaways for the students. The most important takeaways were decided to be:

- Create their own procedure
- Understand the topic well enough that they can teach AFM to other students
- Having a good understanding of the equations. Need math to prove that their idea can work.
- Present work in a way that educates others
- Learn from mistakes/adapt
    - Say what went wrong and how they fixed it

- If you did this again, what would you do better?

We worked in tandem with Dr. Lamprecht to design each portion of the project as we established a clear, detailed timeline of deliverables as seen in *Appendix J*. By doing this, we provided the students in Dr. Lamprecht's course a clear pathway to complete the project with bite sized pieces to aid in spreading the workload. We wanted to be certain that we would be providing the students at OST with the best PBL experience possible.

3.3.4 Outcomes

We created deliverables for Dr. Lamprecht so that he could properly implement the modules into his course for the students. To ensure success, we have decided to include:

- PowerPoint discussing what PBL is
- Timeline
- Rubric for the PBL module
- Post-project student survey

Each deliverable helps enforce the integrity of the module in different ways. The purpose of the additional PowerPoint is to introduce PBL to the students before they dive into the module. Good organization and time management through a timeline is crucial to the pacing of the workload. Finally, we developed a thorough rubric for the project so Dr. Lamprecht and his students would all have a clear outline of the project's expectations.

3.4 Conclusion

To complete this project successfully, we systematically followed our methodology. First, we developed our understanding of how PBL modules work. This was accomplished by interviewing WPI and OST professors about how they run project-based classes. The next step was to understand microtechnology – this allowed us to dive deep into the field and flush out any misconceptions we had about how microtechnology is taught. We worked exclusively with Dr. Lamprecht to narrow down which section of microtechnology is best suited for a PBL module. Finally, we developed a structured way to create a PBL module about microtechnology. Interviewing WPI and OST professors granted us insight on how these types of modules are typically created; surveying WPI and OST students showed us their perspectives. These steps resulted in the creation of a project on atomic force microscopy (AFM) probes.

4 Results

Our goal with this project was to develop a foundational understanding of project-based learning to then create a module for our sponsor at OST. Through interviews with professors from OST and WPI we were able to decide on a topic both feasible for us as students to understand, and for our sponsor to incorporate into his curriculum. The final product was a breakdown for a module surrounding atomic force microscope (AFM) probes, which included: desired outcomes for students, a project timeline, and final deliverables.

When interviewing professors from WPI and OST, we asked questions regarding their personal experience creating and running projects within their different courses. All questions asked are listed in *Appendix A.* Most interviews were performed over Zoom, with one performed in-person on the WPI campus. These interviews helped us gain a foundational understanding of project-based learning from a professor's perspective. Our interviewees gave us an insight into how project-based education is created from start to finish, and we could best go about creating a module of our own.

The logical next step was collecting data on students' opinions surrounding projects. To do so, we administered surveys on Qualtrics to both WPI and OST students. Both student surveys consisted of the questions listed in *Appendix A*. Students were first required to consent to our IRB Informed Consent Script (attached in *Appendix B)* before answering any of the questions. Due to WPI's high concentration of project-based courses, we were able to collect fascinating data from 73 students on their preferences for project types and deliverables. We then used the OST student survey to assess how the six Swiss students felt about projects, along with the topics they tended to struggle with the most. Both were integral in developing our final module.

Through the information gathered from research, professor interviews, and student surveys, we were ready to decide on a topic for the module. Starting with a list of ten options presented by Dr. Lamprecht, we decided on pursuing atomic force microscopy (AFM) probes. This decision was made for three distinct reasons. First, the topic needed to be understandable for our team in our project's limited time. Second, the topic must be covered early in Dr. Lamprecht's curriculum. Third, there needed to be a wealth of information online surrounding the topic so we could conduct efficient research during the project term. Once we had decided on the topic, our module was designed with the collected data in mind. With that knowledge in hand, we decided the final project deliverable would be a physical prototype which would be presented to the class alongside a brief PowerPoint detailing each group's procedure, outcome analysis, and takeaways. For the remainder of this section, we will cover the execution of this plan in greater detail.

4.1 Objective 1: Developing a Foundational Understanding of Project-Based Learning

To develop a successful project-based learning module, we focused on creating a hands-on learning environment to help students strengthen their CORE (competence, organizational, relational, effectiveness) skills. When we created the module, we wanted our information to be based off data from students. We sent out surveys to WPI students to gain a better understanding of how PBL has affected their education and how PBL has helped them learn the course material. When asked to rate the quality of PBL based on their education experience, WPI students rated it on average 7.85 out of ten—as shown in *Figure 5.* This means that most students thought that PBL was a high-quality form of education. Additionally, we asked WPI students how they felt PBL affected how well they learned the material; in *Figure 6* the average response to this question was 4.07 out of five. This implies that WPI students feel that project-based education has helped them learn and better understand the difficulties of their topic. After looking holistically at this data, we became convinced that PBL will help better OST students' education and reinforce these difficult topics. The next step in fully understanding PBL was interviewing professors on their experiences with PBL. The information gained from our interviews with WPI professors was one of our greatest assets. They helped guide our thought process as we investigated how to best cater to the OST students' needs.

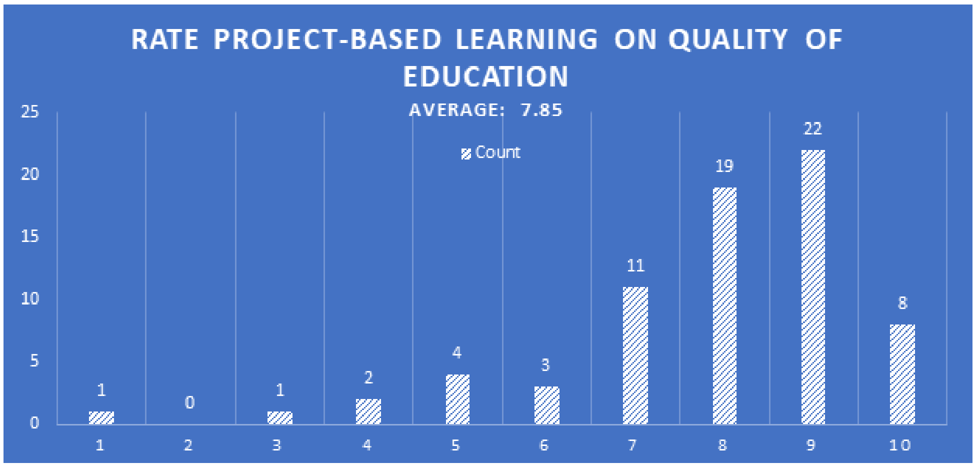

Figure 5: WPI students' rating on how project-based learning improved their quality of education.

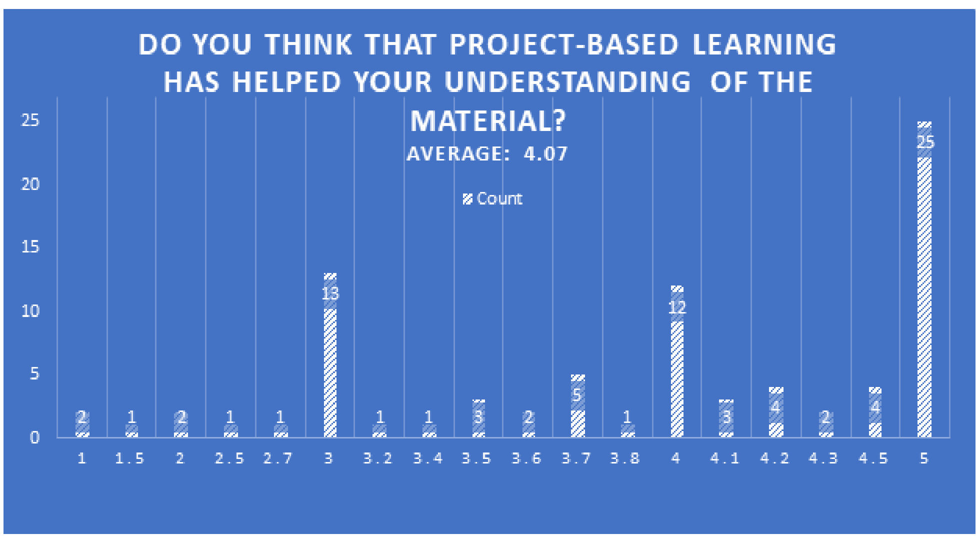

Figure 6: WPI students' rating on how project-based learning has enhanced their understanding of course material.

During our interview with WPI Professor Lewin[1], he advised us to use a backwards design approach when designing a PBL module. This approach was to ensure we keep the end goal in mind when designing how the module would flow with the class. When we began thinking about how to best fit PBL into classes, we originally thought that a continuous project that builds upon itself throughout the semester would be a strong approach. However, after our interview with WPI Professor Doroz[1], we learned that projects that build upon themselves can be problematic. If a student does not fully grasp the material from the most recent project, they will slowly find themselves more and more behind. Understanding this helped us steer clear from that style of PBL. We agreed with Professor Doroz's assessment that a complex PBL module could be hard for students unfamiliar with the process as the semester progressed.

Despite students being unfamiliar with the combination of projects and lecture-based courses, this did not mean they did not experience projects before. OST professor Martin Gutsche[2] went into detail during his interview about the many complex projects OST students complete in their third and fourth years of higher education. WPI professor Francesca Bernardi[2] also told us about her experiences with European education while she studied her bachelors in Italy. She said that while students are expected to remain independent in their studies, they still have opportunities to complete projects in the later years of higher education. Our hope with this module was to introduce these OST students to projects earlier in their degrees. Alongside Dr. Lamprecht, we felt confident we could incorporate a project seamlessly into his current syllabus while allowing his students to experience projects similar to those WPI students enjoy.

4.2 Objective 2: Choosing the Microtechnology Topic

Choosing the microtechnology topic on which to focus our PBL module was done in stages. During our interviews with WPI professors we gained insight into what topics met the standards of PBL. Next, we looked at the OST students' surveys to see what topics they were interested in having turned into projects or what they needed more help understanding. These steps helped us to choose a topic within microtechnology to teach in our PBL module. We took the information learned from our sponsor and narrowed it down to a topic that we could easily build a PBL module around and that would fit within the microtechnology curriculum at OST.

Through analysis of our interview notes, we determined that three professors gave us the most insight into developing the topic for a PBL based class. Those professors were Doctor Don Gelosh[2], Professor Rudra Kafle[2], and Professor Martin Gutsche[2]. Professor Kafle gave us insight on how to adapt a set syllabus to incorporate PBL projects without changing what is taught within a course. This helped us break down Professor Lamprecht's syllabus and discuss what topics can easily have projects tailored to them. Professor Gelosh also emphasized that having up to date information and working with relevant professors and professionals will ensure the quality of the chosen topic.[2]

The next step was understanding how certain topics taught within microtechnology are more suited to PBL and will better aid students' understanding of the subject. Professor Gutsche discussed how using the clean room is a key aspect of microtechnology, but it is difficult to have students working in there every day. When we visited the OST campus, Dr. Lamprecht gave us a tour of the clean room. It took several minutes to change into clothes for the clean room as it is a highly controlled environment where the amount of dust must be kept to a minimum. Because the environment is highly controlled, it means that it is quite difficult and costly to have students working there every day. This reinforced the idea that it would be very difficult to have this project take place within the clean room, as our sponsor explained early on in our conversations. He also mentioned how vital it is that the topic chosen for the

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[2] OST Professor Martin Gutsche Professor of Microtechnology Head of the Process of Technology Competence Area with a PhD in Physics
WPI Professor Francesca Bernardi Assistant Professor of Mathematical Science with a PhD in Mathematics
WPI Professor Doctor Don Gelosh Expert in Systems Engineering Professional (ESEP-Acq) and Director of Systems Engineering with a PhD in Electrical Engineering
WPI Professor Rudra Kafle Associate Teaching Professor of Physics with a PhD in Theoretical Atomic Physics

PBL module is discussed in lecture prior to the project. Additionally, he felt it was important to have the students do their own research on the topics. Professor interviews were not the only source of information we utilized to choose the microtechnology topic, as explained below.

One of the most important things to consider were the students who will work on the project. We sent out a survey to OST students to see what topics they struggled with and what they wanted to do projects on. Considering Dr. Lamprecht's class size tends to be around eight students, our pool of OST students consisted of six students; however, we still received important information about what topics they would be interested in doing a project on. Students specified that they wanted to learn more about sensors, actuators, and uses of microtechnology in medicine. They also talked about how they wanted to get more practical skills out of classes to become more prepared for the work force and gain a deeper understanding of microtechnology.

The final step in the topic selection process consisted in combining what we learned from the interviews and surveys so that we could work with Professor Lamprecht to pick our topic. Professor Lamprecht gave us a list of ten different topics, and we had to narrow down which one would work best. Of the listed topics, the team decided (alongside Dr. Lamprecht) on AFM probes being our focus. We made this decision primarily because of the topic's placement in the syllabus, with it being taught very early in class curriculum. Creating a module for a topic early in the course would limit how complicated the content would be and would open the door for further project creation in the semester if the students enjoyed the experience. Additionally, workloads are generally lighter early in the semester – especially without any thoughts of the final exam and corresponding studying. With this in mind, the project would be more attainable as students will have more free time to dedicate out-of-class. To emphasize this, WPI professor Rudra Kafle quoted Confucius, saying: "If I hear, I forget. If I see, I remember. If I do, I understand." Prototyping a probe would add Professor Kafle's advice into Dr. Lamprecht's class. Including a hands-on portion not only gives students valuable experience with the material but would also help them understand the topic better. Next, we analyzed the OST student surveys to see what topics they wanted to learn about, and, in turn, which could be adapted into a project. We found that sensors and actuators fit these criteria the best. Additionally, we made sure the chosen topic was a relatively simpler subject within microtechnology to ensure the students were less overwhelmed in this inaugural project. All this analysis led us to atomic force microscopy (AFM) probes. AFM probes are widely used in microtechnology to help map the topography of a material. This topic also addresses the students' tendency to struggle with very small components, as AFM probe tips are generally ten-to-twenty nanometers tall.

4.3 Objective 3: Creation of the Project-Based Module

Once we gathered additional information on AFM probes, we learned that there is a vast array of probe types and began developing the final deliverables. As Professor Gelosh explained in our interview, it is always best to begin with the outcomes of the project and work backwards from there. Through several discussions amongst our group members and Dr. Lamprecht we decided on a model-based project. This final deliverable will be an enlarged model of their assigned AFM probe. Since OST students had expressed in our survey that the size of these microtechnology structures was often a source of confusion, having them produce an enlarged model would allow the components of the probe to be easily seen with the naked eye. The students will be split into groups of three, each assigned with their own unique probe type to research and build. Alongside some supplementary educational content as aid, the groups of students will then be left to work independently. Each team will be expected to conduct research to develop their own procedure for the creation of the probe.

The students will be required to create two presentations, a preliminary design review (PDR) and a critical design review (CDR). The PDR will take place within the second week of the project. Its main goal is to give Dr. Lamprecht the opportunity to check in with groups and help steer them back on track if they are straying from project goals. The PDR can be seen as a halfway check-in for the project. The CDR will be the final presentation for the project. This will take place at the end of the project that is set up to last about four weeks.

Each presentation will have slightly different requirements. For the PDR presentation, students are required to include the information in *Table 4*. Students will be required to show their calculations, engineering procedures, and designs (sketches or blueprints) for their probe. The main purpose of the PDR is an opportunity for Dr. Lamprecht to check-in and make sure the teams are making good progress. Calculations and designs are required so that Dr. Lamprecht can evaluate the design of the teams' probes and provide feedback. The engineering procedures are required so that Dr. Lamprecht can judge whether the students are ready to have their probe manufactured. After the PDR presentation, students will continue their research, manufacture their probe, and create the CDR presentation.

Table 4: Requirements for the Preliminary Design Review (PDR) presentation Dr. Lamprecht's students must deliver halfway through the project.

Criteria for PDR Presentation:	
Calculations	This slide will show the math they needed to figure out how to make the probe
Engineering Procedures	This slide will have the procedure that the students will use to create their probe
Design (Sketches/blueprints)	This slide will show their designs for their probe with sketches and labeled dimensions

The CDR presentation is required to contain the information listed in *Table 5*. The CDR is designed to be a continuation of the PDR presentation. Students will continue their research after the PDR presentation and learn more about the applications of the probe they are studying. The CDR is asking students to present on an application of the probe. This will hopefully familiarize the students with practices that are done in the industry. As part of the PBL experience, the teams will also be required to talk about the challenges that they faced working together, and how they overcame them. Finally, in the CDR presentation the students will be required to show the final design of their probe and the prototype.

Table 5: Requirements for the Critical Design Review (CDR) presentation Dr. Lamprecht's students must deliver following completion of the project.

Criteria for CDR Presentation:	
Background	This slide will include any previous research they needed to complete the project
Applications of Probe	This slide will include one application of the probe Students will go in-depth about the specifications of the probe application
Engineering Procedures	This slide will have the procedure that the students developed to create their probe
Calculations	This slide will show the math they needed to figure out how to make the probe
Challenges	This slide will list challenges that the students encountered during the project, students should go in depth about how they adapted and grew from these challenges
Prototype of the Probe	This slide will show their final probe prototype, its dimensions, and sketches

4.3.1 Project Grading

One of the most important deliverables for Dr. Lamprecht was our grading rubric. In our discussions with Dr. Lamprecht, we decided to use a ranked scale for the sections on our rubric. The sections on which we decided to evaluate students' performance are as follows: presentation skills, content, knowledge of topic, and the final model. The rubric that was given to Dr. Lamprecht can be seen in *Appendix I*.

The grading section of presentation skills will contain several categories that will be considered. The first consideration when grading the presentation skills section is public speaking. Public speaking is a very important CORE (competence, organizational, relational, and effectiveness) skill that is beneficial for students in any field. Students also need to learn how to work well in teams, and having teamwork being part of the grading scale will incentivize students to put effort into working well with their teammates. The presentation skills section of the rubric will be weighted less than the other sections of the project. This is because from looking at our OST student surveys, we learned that the students do not have a lot of experience in group projects, and these skills will be very new to them. We wanted this module to be a smooth transition for the students, and we knew that we needed to mitigate drastic changes that may decrease the level of enthusiasm amongst students.

The content section of the grading rubric contains many grading categories, such as: background research, applications of probe, engineering procedures, equations, challenges, and the prototype of the probe. These categories will be graded with the highest weight, as students will be used to them. This section of the rubric will focus on the required materials for the CDR presentation.

Gauging students' knowledge of the topic is hard, so we looked to our research on project-based learning for insight. We realized that the most effective way to reinforce knowledge of a topic is to teach it to another person, so we decided that the students would have a question-and-answer section at the end of their CDR presentation. This will allow the students to show their knowledge of the topic to Dr. Lamprecht as well as let others in the class engage with the speakers. This section will also be weighted highly, as Dr. Lamprecht wants to make sure that the students fully understand the information that they spent several weeks researching.

The last section of the grading rubric is the students' final project, i.e., the AFM probe prototype. Dr. Lamprecht will develop a protocol to test the requirements of each probe to make sure the students' prototypes are functioning properly. This step will allow students to become more familiar with the normal testing procedures that are found in the industry. Dr. Lamprecht will be able to give the students feedback on their probe design, just as if they were working in the industry. The hope is that this rubric will be used as a springboard for assessing future project-based learning developed at OST as it can be easily adapted to fit almost any project. The rubric is not the only thing that will help Dr. Lamprecht teach this PBL module, he will also need a detailed timeline to stay on track.

4.3.2 Project Timeline

The project will take place over four weeks with a week 0 at the beginning to introduce PBL. Dr. Lamprecht only meets with his students once a week for 2.25 hours, so we had to design a timeline that fits that schedule but also made sure the students had hard deadlines. The project will begin with Dr. Lamprecht introducing AFM probes and the project expectations to the students. There will be a PDR presentation in week two and the CDR presentation in week four. The full timeline of the project can be found in *Appendix J*. The probe prototypes will be manufactured during week three. In case the creation of the probes takes longer than expected week four of the project can be extended until the probes are ready.

4.3.3 Project Feedback

To gauge the success of this project-based module, Dr. Lamprecht wants to assess whether students benefited from its integration. Success of the project cannot be gauged off student grades, as PBL is a completely different delivery method than what students are used to, so we must turn to the students and obtain their feedback. We provided Dr. Lamprecht with a sample survey to administer to his students after the module has been completed. The survey questions can be seen in *Appendix K*. This survey would allow Dr. Lamprecht to see if his students benefitted from the implementation of the AFM probe project. This feedback will be used to gauge if students are finding PBL to be as useful as what WPI students think it is.

5 Conclusions & Recommendations

Our sponsor, Dr. Tobias Lamprecht, is a professor at the Eastern Switzerland University of Applied Sciences (OST). At this university they teach Systems Engineering – a field in STEM. Teaching STEM is not simple, technology changes at a rapid pace and the education for this technology changes just as rapidly. Dr. Lamprecht wanted to change how OST currently approaches education and integrate projects earlier in the curriculum. The goal of this project is to develop a project-based learning module that will assist the Eastern Switzerland University to enhance its systems engineering students' learning experience and improve their understanding of the material.

5.1 Methods

Before we were able to start building a project-based learning (PBL) module, we needed to gather information about how PBL works and people's experience with it. We interviewed four WPI professors who told us their experiences teaching with PBL and what steps they use to create PBL modules.

Additionally, we interviewed one WPI professor and one OST professor who were able to give us information about schooling in Europe and go into detail about how education works at OST.

In order to gather student opinions, we sent out separate surveys to WPI and OST students. Students at WPI gave us information on their prior engagements with PBL, along with their likes and dislikes about projects being used in lecture-courses. The OST students informed us on what topics they struggle with and what they would want a project done on.

5.2 Results

The information from the interviews and surveys allowed us to conclude that PBL is a justifiable way to improve teaching microtechnology. The results from the surveys, as shown in *Figures 5 & 6,* indicated that students greatly benefit from having PBL in their classes. The next step in the process was to take this information and decide what project format would suit microtechnology the best. After following advice from professors and taking in student experiences, we concluded that a physical prototype paired with a PowerPoint presentation was the best format.

Our next step was to narrow down what microtechnology topic would benefit the students most. Using the information from OST students' surveys, professor interviews, and discussions with our sponsor we choose atomic force microscopy (AFM) probes as the topic for the project. Students would create a glass AFM prototype and corresponding PowerPoint following a rubric and timeline, listed in *Appendices J & K* respectively.

By creating this module, our end goal was to deepen students’ understanding of microtechnology topics, improve their CORE skills, and better prepare them for the workforce. To gauge whether the project carried out these objectives we created a Qualtrics survey for Professor Lamprecht to give to his students following the module (the questions can be found in *Appendix K*). Additionally, during the project itself, the students will be required to fill out a team assessment; during the assignment team members will be required to discuss how the group is functioning. The results of these assessments would help guide any continuations of this project and help Professor Lamprecht design his own PBL modules.

5.3 Recommendations

For any future IQP projects related to creating a PBL module, we recommend interviewing a variety of professors at WPI to gain insight into their experiences. The quality of information gathered from these interviews would be more consistent if the professors studied in a related field to the project topic. Additionally, throughout the entire process, it is important to keep student opinions in mind. For future modules, having the students complete Team Assessments – a process where students provide feedback on everyone in their group and comment on the group dynamic – would be beneficial to ensure the work is completed evenly. In the end, the module is for the students and keeping their interests in mind would ensure the project helps the students.

5.4 Impacts

After implementing this project into Dr. Lamprecht’s course, we hope that it will act as a springboard for future PBL modules at OST. From our experiences at WPI, we have found that PBL does wonders with engineering classes, and we want to share that with the students at OST. PBL allows students to develop better CORE skills that are valued by employers. We hope that if this introduction to projects in lecture-based courses is enjoyed by the students, other professors at OST will catch on and more students will gain the benefits of PBL modules. We hope that, through this project, we will open the door to an entirely new set of learning experiences for students at the OST. Our final wish is that we can give these students the opportunities that we ourselves are afforded at WPI.

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7 Appendices

7.1 Appendix A: Survey/Interview Questions

Questions for WPI Professors:

- What was the hardest part about designing a project-based learning module?
- How has teaching your module changed over time?
- Have you made changes between the times you have taught it?
  - What were those changes?
  - What made you decide to change it?
- What style of projects work best with your class?
  - Several small projects?
  - One large project?
- Which one of your projects was your students' favorite?

Questions for OST Professors:

- Have you considered incorporating projects into your classes? What has held you back from doing so up until now?
- How do you think adding a project to your course will affect your students' involvement/depth of knowledge in the course?
- Have you employed any projects in your classes during your teaching career? If so, what format were they?
- What is your preferred method of learning? Teaching?
- If you were to do group projects in your classes, how do you think it would affect student in class participation?
- Do you think hands on experiences improve students' learning?
- When considering a potential project in your engineering classes, what do you think would be a reasonable length of time for the project to span? (3 weeks? 5 weeks? Etc.)
- Would you ever consider having a final project replace the final exam?
- Would you consider a lab or a project to aid as homework?
- Can you think of what materials and equipment you may need to complete a project for your class? How accessible is this on a semester or year-to-year basis?
- Do you think that adding a project to your course will change the amount of effort needed to teach it?

Questions for WPI Students:

- What have you enjoyed most about project-based courses?
- What classes that projects offered at WPI?
- Do you think that hands-on projects have helped your understanding of material?
- Rate project-based learning on a scale of 1-10
- Is there a project-style that you despise? Why?

Questions for OST Students:

- What is the hardest part of microtechnology to understand?

- Have you done any projects in your school career? If so, what format were they?
- If you had to do a project related to microtechnology, what topic would you do it on?
- What is your preferred method of learning?
- What do you hope to get out of this class?

Professor Bernardi Questions:

- What is the main difference between schools in Europe and schools in America?
- How drastic was the classic classroom style and a project-based classroom in Europe versus America?
- Will we have to modify the project style to European classes, or can we use an American Style approach?
- Are the out of class expectations for schoolwork different between the two?
    - What is the typical workload per week for students in Europe?
    - What kinds of homework are typically assigned?
- What is the grading style in Europe?
- How can we best structure the module?
    - What would they be more used to?

7.2 Appendix B: Consent Script

Informed Consent Agreement **for Participation in a Research Study**

Investigator:

Worcester Polytechnic Institute IQP team. This team includes Chelsea Chang, Joelynn Petrie, Evan MacGregor, & Brandon Simpson. Our advisor is Professor Francesca Bernardi.

Title of Research Study: *Microtechnology: The Project-based Approach*

Sponsor: Dr. Tobias Lamprecht

For more information about this research or about the rights of research participants, or in case of research-related injury, contact:

WPI IQP Team:

Chelsea Chang, Joelynn Petrie, Evan MacGregor, & Brandon Simpson

gr-pbl-d21@wpi.edu

Advisor:

Francesca Bernardi

fbernardi@wpi.edu

IRB Chair:

Professor Kent Rissmiller

508-831-5019

kjr@wpi.edu

University Compliance Officer:

Michael J. Curley

508-831-6919

mjcurley@wpi.edu

Introduction:

You are being asked to participate in a research study. Before you agree, however, you must be fully informed about the purpose of the study, the procedures to be followed, and any benefits, risks or discomfort that you may experience as a result of your participation. This form presents information about the study so that you may make a fully informed decision regarding your participation.

Purpose of the study:

The purpose of this study is to obtain necessary information to design our own project-based learning module. This module with go over information needed to enhance a microtechnology course.

The goal of this proposal is to develop a project-based learning module that will assist the Eastern Switzerland University (OST) to enhance its systems engineering students' learning experience and improve their understanding of the material.

Procedures to be followed:

If a subject chooses to participate in our project, we will follow one of the two procedures listed below:

Professor Interviews:

All of these interviews will be conducted over a Zoom call format, unless otherwise noted. We will require all participants to provide their name, age, and an email for contact purposes. During these interviews we will take extensive notes, and if permitted we will record the interview through the Zoom software. These interviews will not last more than 30 minutes.

Student Surveys:

These surveys will be administered through Qualtrics. In the survey we will require that students provide their age (for legal reasons) as well as their name and an email. All surveys should not take more than 10 minutes to complete. If we receive date from a student that requires more information, we will reach out to them through email. In the case that the information needed cannot be answered through email communication we will set up a 15-minute interview over Zoom with the student to gather the clarifying data.

Benefits to research participants and others:

There will be no compensation for participating in this study, monetary or otherwise. The information gathered for this project can help make project-based learning better, not only at Eastern Switzerland University (OST), but potentially at WPI as well. Any participants that are actively interviewed may get feedback about project-based classes or gain some insight on the matter.

Risks to study participants:

Risks and discomforts related to this research are minimal and would only include any previously had stresses or discomforts related to teaching or learning through project-based classes.

Alternative procedures or treatments available to potential research participants:

If a participant is uncomfortable or unable to do a Zoom interview, we will provide alternative forms to gather data, such as: a survey through Qualtrics, or an email-based conversation.

Record keeping and confidentiality:

The information collected for this project will be stored in a separate file on our Microsoft Teams account. Records of your participation in this study will be held confidential so far as permitted by law. However, the study investigators, the sponsor or it's designee and, under certain circumstances, the Worcester Polytechnic Institute Institutional Review Board (WPI IRB) will be able to inspect and have access to confidential data that identify you by name. Any publication or presentation of the data will not identify you.

Compensation or treatment in the event of injury:

You do not give up any of your legal rights by signing this statement.

However, if you suffer an injury that requires any treatment or hospitalization as a direct result of this study, the cost for such care will be charged to you. If you have insurance, you may bill your insurance company. You will be responsible to pay all costs not covered by your insurance. Worcester Polytechnic Institute will not pay for any care, lost wages, or provide other financial compensation.

If you require any further information, please refer to the contact list stated at the top of the document.

Your participation in this research is voluntary. Your refusal to participate will not result in any penalty to you or any loss of benefits to which you may otherwise be entitled. You may decide to stop participating in the research at any time without penalty or loss of other benefits. The project investigators retain the right to cancel or postpone the experimental procedures at any time they see fit.

By signing below, you acknowledge that you have been informed about and consent to be a participant in the study described above. Make sure that your questions are answered to your satisfaction before signing. You are entitled to retain a copy of this consent agreement.

___________________________ Date: ___________________

Study Participant Signature

____

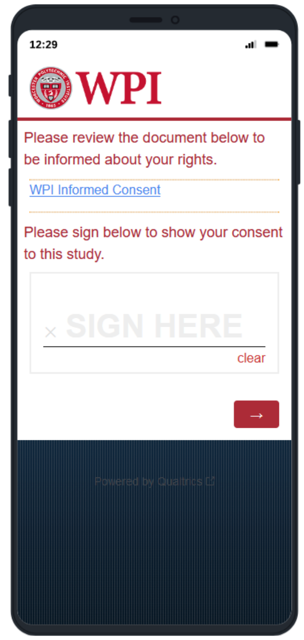
Study Participant Name (Please print)

____________________________________ Date: ___________________

Signature of Person who explained this study

Special Exceptions: Under certain circumstances**,** an IRB may approve a consent procedure which differs from some of the elements of informed consent set forth above. Before doing so, however, the IRB must make findings regarding the research justification for different procedures (i.e., a waiver of some of the informed consent requirements must be necessary for the research is to be "practicably carried out.") The IRB must also find that the research involves "no more than minimal risk to the subjects." Other requirements are found at 45 C.F.R. §46.116.

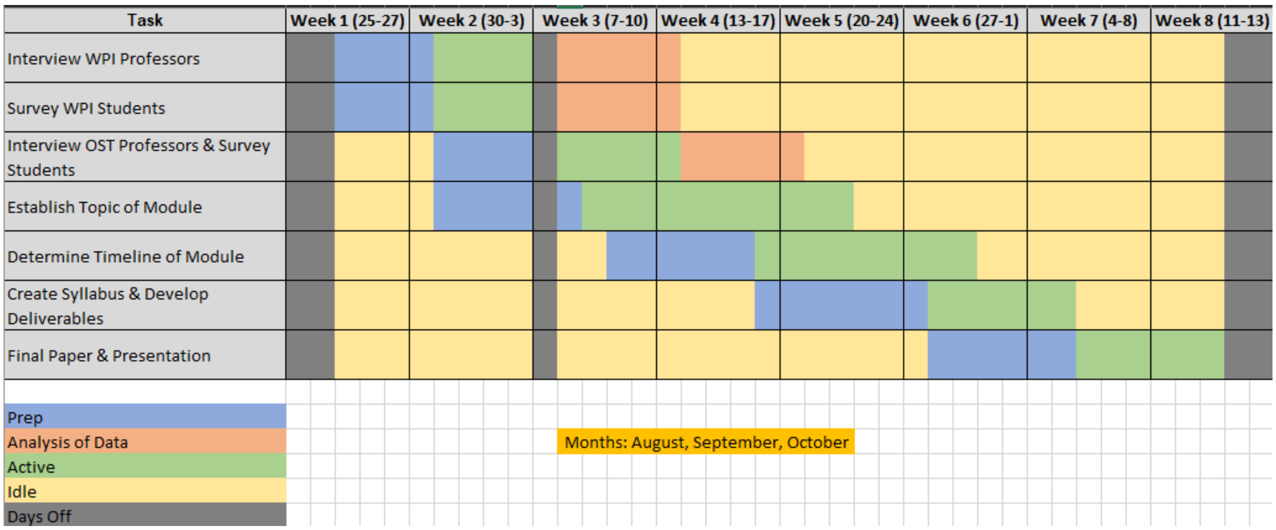
7.3 Appendix C: Sample Survey Consent



Note: The hyperlink in the survey links to our team's consent script

7.4 Appendix D: Gantt Chart

Table 6: Our Team Gantt Chart for the term.



7.5 Appendix E: Department Shorthand Names

Table 7: List of WPI department shorthand names.

Shorthand Name	Department Name
AR	Art
Bio	Biology
BME	Biomedical Engineering
BUS	Business
CE	Civil Engineering
CH	Chemistry
CHE	Chemical Engineering
CS	Computer Science
DS	Data Science
ECE	Electrical and Computer Engineering
ECON	Economics
EN	English
ES	Engineering Science
ETR	Entrepreneurship
GN	German
GPS	Global Project Seminar
GSWS	Gender, Sexuality, & Women's Studies
HI	History
HUA	Humanities
IMGD	Interactive Media and Game Design
INTL	International Studies
IQP	Interactive Qualifying Project
MA	Mathematics
ME	Mechanical Engineering
MKT	Marketing
MQP	Major Qualifying Project
MU	Music
OIE	The Business School
PH	Physics
RBE	Robotics Engineering
WR	Writing

7.6 Appendix F: WPI Student Survey Data

Question 1 (Evan):

Table 8: WPI students' ranking of favorite aspects of project-based learning.

Aspect of PBL	Times chosen	Percent Chosen
Problem-Solving	51	22.37%
Teamwork	50	21.93%
Project Management	49	21.49%
Critical Thinking	33	14.47%
Social Skills	30	13.16%
Constructive Criticism	12	5.26%
Other	3	1.32%

Other:

- I Just like making friends
- Getting close with the team
- I don't enjoy project-based courses

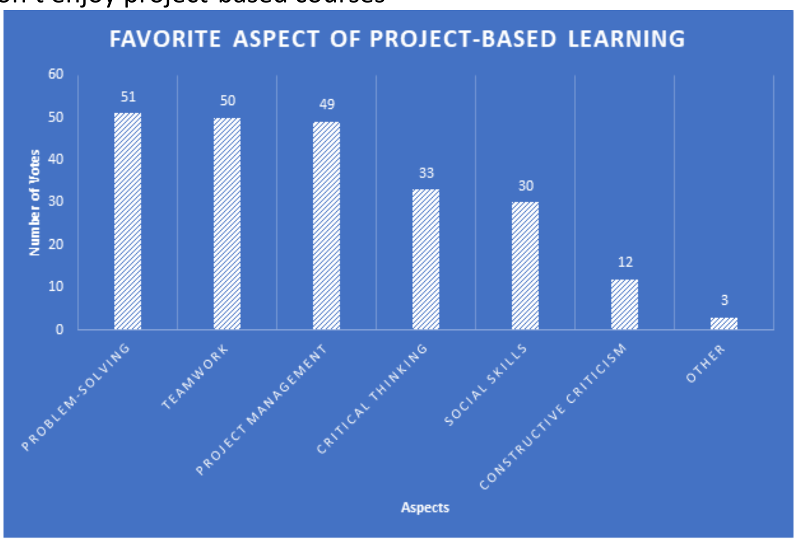


Figure 7: WPI students' ranking of favorite aspects of project-based learning

Question 2 (Brandon):

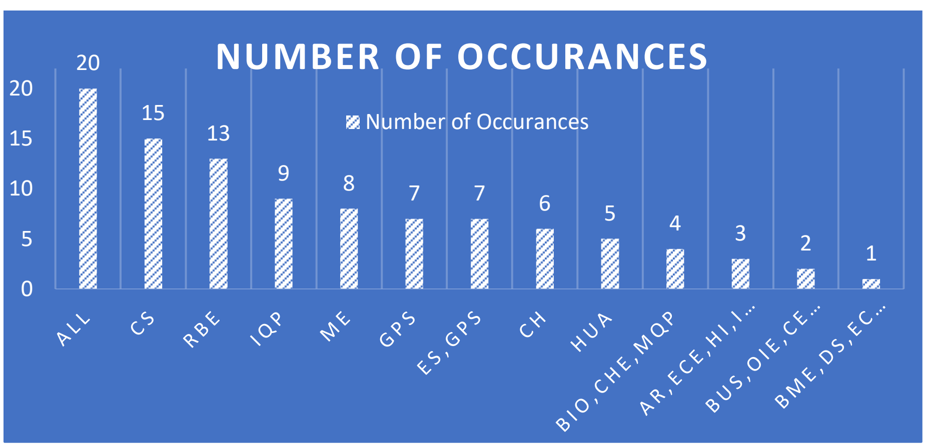


Figure 8: Number of occurrences of projects within different departments at WPI.

Table 9: Number of occurrences of projects within different departments at WPI.

Department	Bio	ME	ETR	ECE	CS	GPS	RBE	IQP	ES	MQP	HUA	PH	HI	IMGD	CH	MA
Count	4	8	1	3	15	7	13	9	7	4	5	2	3	3	9	3
Department	OIE	BUS	ECON	MU	GN	CHE	AR	WR	GSWS	DS	BME	INTL	EN	MKT	CE	All
Count	2	2	1	1	1	4	3	1	2	1	1	1	1	1	2	20

Quotes:

- "Almost all of them, harder to think of ones that didn't"

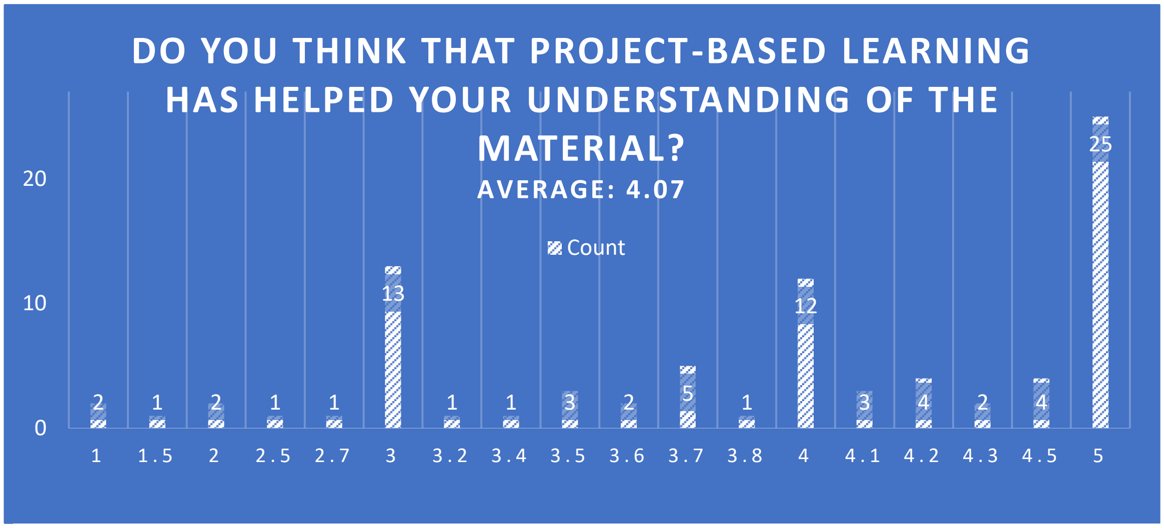


Figure 9: WPI students' rating on how project-based learning has enhanced their understanding of course material.

Question 3 (Brandon):

Table 10: WPI students' rating on how project-based learning has enhanced their understanding of course material.

#	1	1.5	2	2.5	2.7	3	3.2	3.4	3.5	3.6	3.7	3.8	4	4.1	4.2	4.3	4.5	5
Count	2	1	2	1	1	3	1	1	3	2	5	1	12	3	4	2	4	25

Question 4 (Brandon):

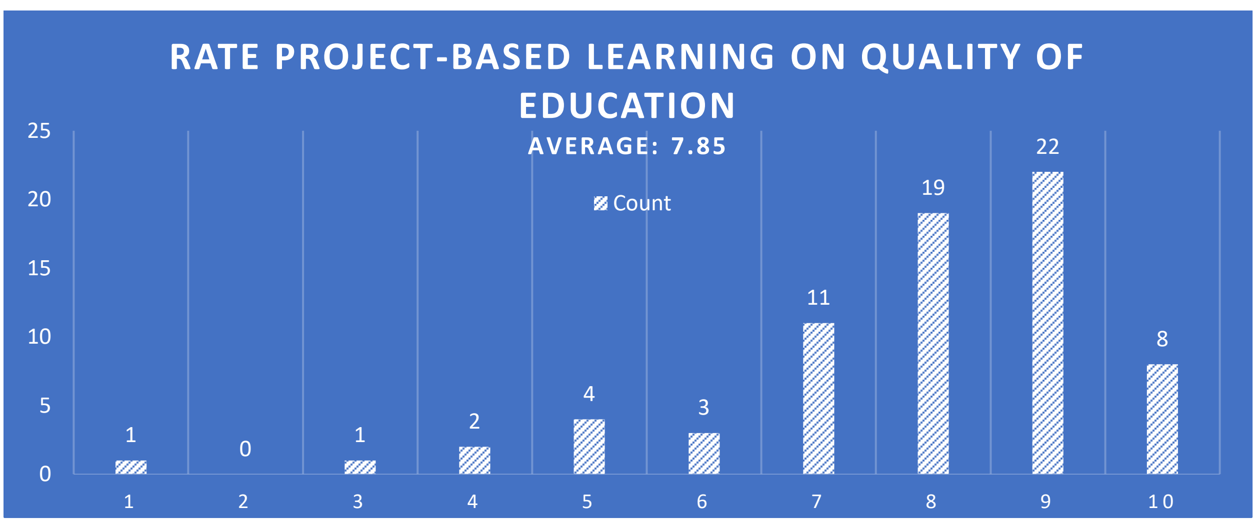


Figure 10: WPI students' rating on how project-based learning improved their quality of education.

Table 11: WPI students' rating on how project-based learning improved their quality of education.

#	1	3	4	5	6	7	8	9	10
Count	1	1	2	4	3	11	19	22	8

Question 5 (Evan):

Table 12: WPI students' most disliked project types.

Project Style	Times Chosen	Percent Chosen
Solo PowerPoint/Speech	23	31.51%
Formal Report	17	23.29%
Group PowerPoint/Speech	14	19.18%
No/NA	12	16.44%
Posters	5	6.85%
Building a Demo	2	2.74%

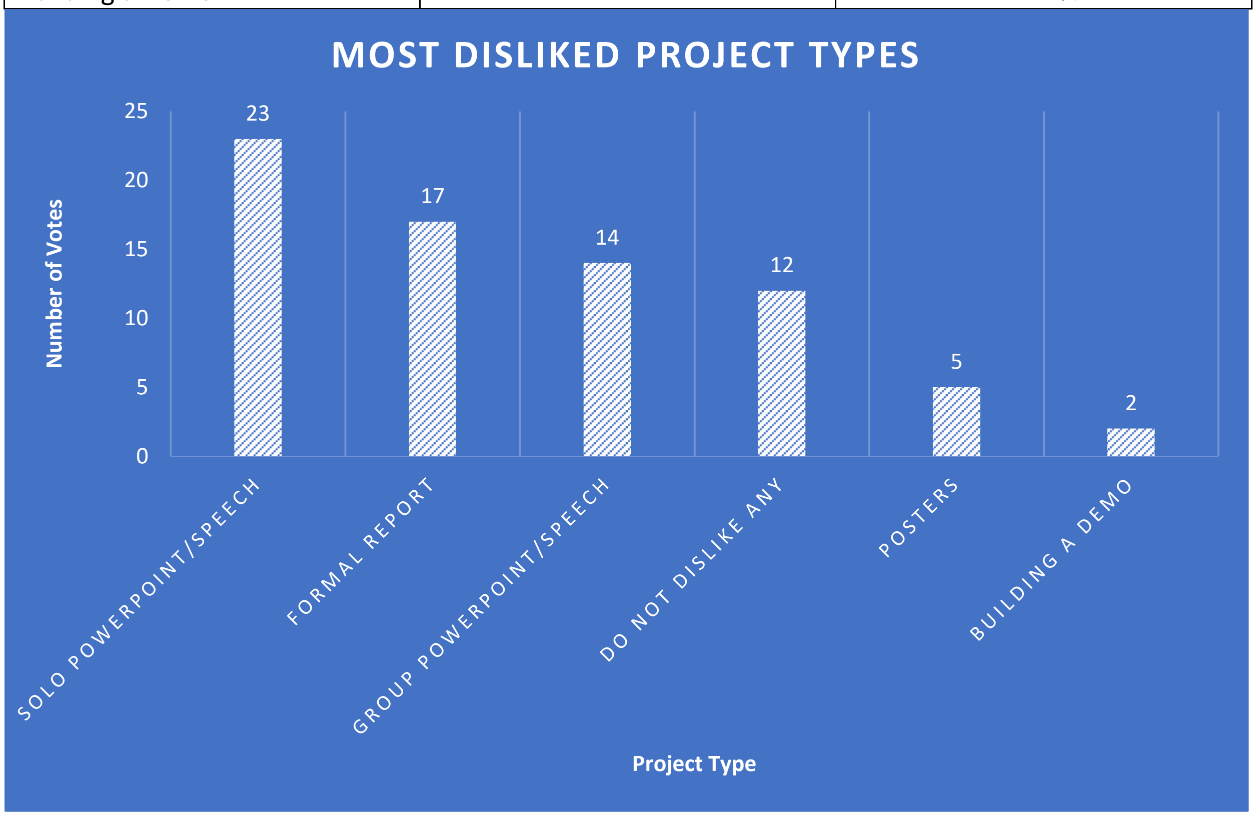


Figure 11: WPI students' most disliked project types.

Question 6 (Evan):

Table 13: WPI students' most disliked project types explanation.

Project Style	Notable Comments
Solo PowerPoint/Speech (31.51%)	• Anxiety related to presenting alone • Feeling more thought goes into the nervousness of presenting alone than the content • Boring • No rapport, all eyes on you • Feels scripted and unnatural • Doesn’t feel like a project • Presenting is very similar to lecture style, so it doesn’t change the experience for those listening in the class • Too dependent on confidence & public speaking ability rather than content
Formal Report (23.29%)	• Feels like just another assignment • Dislike writing • Different writing styles among group members so the papers rarely feel cohesive • Hard to distribute work efficiently • Members only focus on learning their own section, so you don’t understand the whole topic
Group PowerPoint/Speech (19.18%)	• Anxiety related to presenting • Feeling more thought goes into the nervousness of presenting alone than the content • Boring • Feels scripted and unnatural • Doesn’t feel like a project • Presenting is very similar to lecture style, so it doesn’t change the experience for those listening in the class • Too dependent on confidence & public speaking ability rather than content • Slides end up being done separately, rarely do group members understand everything
No/NA (16.44%)	
Posters (6.85%)	• Require artistic ability • It’s an art project, don’t feel like much is learned
Building a Demo (2.74%)	• Hands get shaky around others, makes it hard to build • Don’t like hands on • Too much effort

7.7 Appendix G: OST Student Survey Data

Concerns:

- Everything is so small
- Physical Principles of photonics
- To build up a model that describes the sensors or actors
- Plasma coating and formulas
- Electronics and calculating sensors or actors

Projects that Have Been Done:

- Usually 4 inch, 6 or 8 inch.
- Theoretical preparation, implementation, analysis. EX: capacitive pressure sensor
- Training practical skills in the lab – photolithography, coating tech, etching
- Micro structuring – had to document everything that happened – teams of 2-3. Preferred those that lasted the whole semester rather than a couple weeks.

Project they would want:

- Introducing new tech in convenient process
- Biomedical tech – lab on chips, microfluidics
- Build a sensor or actor
- Sensorics or medicine
- Sensors/actors

Preferred Method of Learning:

- Practical project work to consolidate theoretical knowledge
- Classic lectures in combo with project in lab. Lab helps to internalize a topic
- Learning by doing
- A mix of hands-on learning through projects and demonstrations. But also, theory classes with lectures and not self-study

What do you want out of the class:

- Practical education in microtechnology that makes one competitive on the job market
- A broad knowledge of microtechnology, know where to go in the future
- Learn skills that enable me to work in the field of microtechnology
- Some basic competence at engineering work in any microtechnology field

7.8 Appendix H: Professor Interview Data

7.8.1 Don Gelosh

Interviewers: Brandon, Joelynn, Chelsea, Evan
Interviewee: Donald Gelosh
Note Takers: Evan and Joelynn
Date: September 2, 2021
Time: 10:00am – 11:00am EST
Location: Zoom
Interviewee has consented to have this interview recorded via zoom
Analyzed by: Joelynn

Key

Objective 1: Understanding PBL

Objective 2: Developing the topic

Objective 3: Creating the Module

Questions and Notes (Joelynn)

- What courses do you teach at WPI?
    - Systems thinking course, 585, mainly does graduate courses.
    - Most courses are grad level and few are undergraduate course
- What was the hardest part about designing a project-based learning module?
    - Getting the teams set up and getting the teams set up to work together.
    - Most team stuff are taught online
        -
    - Its easier to integrate the project into the course then doing it
        - Just know what outcome you want and build from that
    - Electron Microscope
    - He just did experimental things so they didn't use a clean room because it was just learning. Definitely use bread boards
        - AND need to see if they have a laser engraver
    - Definitely no manufacturing things but models
    - No projects only modeling online. No actually labs
- How has teaching your module changed over time?
    - Sys 501 course used to be based off of a teacher at John Hopkins. But then it was getting old so he has to work with international systems of engineering council. So there is a handbook to teaching courses, but kept in a lot of projects.
        - Main thing to know is what the end outcome is and work backwards from that
            - Definitely do small teams – two teams of 4
- Have you made changes between the times you have taught it?
    - What were those changes?
    - What made you decide to change it?
- What style of projects work best with your class?
    - Depends on the course. They have one individual project where there is 3 pieces. And there is a couple team projects. The final team project is putting together slides in what System engineering is and teaches to younger students
    - 585 – teams of 3-4 each. Its broken up similar to IQP slowly works it up to the end goal.
    - Several small projects?
    - One large project?
        - One project with things building up to it. Break it up into pieces and use what you do in lectures.
- Which one of your projects was your students' favorite?

    - In general students reach best to seeing the results of their work. Getting to see the end result is more satisfying then just a paper. And being able to test the theories. And work in models so they can see what the end result will be
    - It can be a really simple controller. It doesn't need to be complex.
- **Biggest thing you need is patience and knowing what he wants the students need to know by the end of the course. Prioritize things. Then work backwards**
- **"Start with the end in mind"**

Questions and Notes (Evan)

- What courses do you teach at WPI?
    - Sys501, Sys540, Sys585, primarily graduate level courses
- What was the hardest part about designing a project-based learning module?
    - Getting teams setup and collaborating efficiently
    - Projects are generally done remotely online, so time zones must also be considered
    - Bread boards should be used
    - Was able to tack their work onto the end of chip developments by major manufacturers
    - Only did models
- How has teaching your module changed over time?
    - Sys501
        - Worked with international council for systems engineering to use their course handbook
        - Revamped course with use of handbook, now involved the council's certification being an end goal of the course
        - Start from end goal and work back
        - Do not have group sizes over 4-5
        - Final project involves producing a presentation to teach elementary school students what systems engineering is all about (forces students to deeply understand content so they can aptly describe the field to the kids)
    - Start with requirements, then move to plans, then move to models, then document, then operational test
- Have you made changes between the times you have taught it?
    - What were those changes?
        -
    - What made you decide to change it?
        -
- What style of projects work best with your class?
    - Several small projects?
        - Groups of 3-4 are best, function like IQP
    - One large project?
        - Have several small buildup assignments throughout course leading up to the final project, leads to most complete understanding of content
- Which one of your projects was your students' favorite?
    - Students enjoy seeing tangible results of their work (i.e. producing a drone more fun than producing a paper)
    - Anything that can be tested or simulated to show quality of work in a real application is the most rewarding

    - Has alarm systems or coffee makers as final projects; seems simple but being able to make something everyone is familiar with is exciting for students
- Any advice for us?
    - "A good supply of patience"
    - Lay out very clearly what you want the students to learn by the end of the project
    - Develop architecture of course after defining end result

Table 14: Major take-aways from interviews sorted by objective (Don Gelosh).

Major Take-Aways Sorted by Objectives		
Objective 1	**Objective 2**	**Objective 3**
No information related to this topic was provided in the interview*	When picking what topic will be turned into a PBL, the teacher needs to consider if that information is still up to date. Professor Gelosh ran into the issue of information for one of his courses was out of date. He then worked with the International Council of Systems Engineering to revamp the course. This type of assistance might be something we look into for our PBL module.	One of the hardest parts of implementing a PBL class is getting the teams to work together and collaborating efficiently. It is even harder to encourage teamwork when working remotely. If you do an online based project, use experimental projects and implement kits – such as those that use breadboards – instead of utilizing clean rooms. When you create the groups, it is best to not have more then 4-5 people per group.
		When creating a project, it is always best to start from the end goal and build the module off those goals.
		Allowing students to see the progress they are making and directly applying the material they are learning to a project, makes students interact more in class.
		The most important things to keep in mind are patience and what your end goals are.

7.8.2 Rudra Kafle

Interviewers: Brandon
Interviewee: Rudra Kafle
Note Takers: Brandon
Date: September 4, 2021
Time: 10:00-10:30am
Location: Zoom
Interviewee has consented to have this interview recorded via Zoom
Analyzed by: Joelynn

Key

Objective 1: Understanding PBL

Objective 2: Developing the topic

Objective 3: Creating the Module

Questions and Notes

- What was the hardest part about designing a project-based learning module?
  - Wide range of students
  - Some students world rather exams
  - A lot of preparation
    - Instructors ahead of time
  - "Engage learners effectively"
  - Integrating in astrophysics
    - 25% of grade is from projects
  - Convinve students that projecs are beneficial
  - Make the students think in a new way
- How has teaching your module changed over time?
  - 29 years
  - Came to us as grad TA
  - Nepal – lectuers
  - WPI 2015
    - Started with lectuers
      - Not everyone was engaged
    - 2017 studio physics started
      - 17 students
      - Labs integrated
      - 2018 got rid of labs and started simulations
      - Worksheets
      - PLAs assist in studio physics
    - Different kinds of projects
      -
- Have you made changes between the times you have taught it?
  - Standard cautologe syllabus cannot change
  - Upgrade it every year
  - Video quizzes
  - 1980s videos with a few questions
    - Peer responses
  - Visualization tools
  - Collaborative problem solving
  - Engaging more and more each year
- What style of projects work best with your class?
  - Depends on the length of the course
  - Shorter

        - Less challenging but engaging
    - Astrophysics
        - Peer revied journals
    - “If I hear I forget, if I see I remember, if I do I understand”
    - Theoretical project
        - Toy model
- Which one of your projects was your students’ favorite?
    - MQP
    - Give a guideline
    - Interstellar work
    - Students come up with project ideas
    - Independent study
- Any advice?
    - Depends on the nature of the courses
    - Look at the size of the class
    - Theory based or skill based
    - Small class
        - More manageable for lab-based projects
        - Designing teaching tools
        - Developing some components
        - Using many other components

Table 15: Major take-aways from interviews sorted by objective (Rudra Kafle).

Major Take-Aways Sorted by Objectives		
Objective 1	**Objective 2**	**Objective 3**
No information related to this topic was provided in the interview*	Sometimes when you are developing your topic you are limited by a standard syllabus that cannot be changed. You can alter the way it is taught (with limitations on how), but not the information provided.	When creating a module, it is hard to fit every student's needs and wants. Each student also has their own backgrounds in the subjects and preferences on how they want to earn their grades.
		The style of project depends on the length and type of the class. But typically, a shorter, less challenging project works best. Having students do any projects helps them better understand the material greatly, no matter the class.
		Having smaller classes make PBL classes easier to manage and you can focus more on each group. It can also allow you to develop more tools and components to use in the class.

7.8.3 Francesca Bernardi

Interviewers: Brandon, Evan, Joelynn, and Chelsea
Interviewee: Francesca Bernardi
Note Takers: Joelynn
Date: September 7, 2021
Time: 4:30 pm – 5:00 pm
Location: Zoom
Interviewee has consented to have this interview recorded via Zoom
Analyzed by: Joelynn

Key

Objective 1: Understanding PBL

Objective 2: Developing the topic

Objective 3: Creating the Module

Questions and Notes

- What is the main difference between schools in Europe and schools in America?
  - The educational structure is very different. (This is for the Italian experience)
  - Students choose major before you start and it's the only classes you take are in that major.
  - The only project she did was more similar to an MQP and that was specific for her major. The length of the project depends on the major. Hers was an experimental project.
- How drastic was the classic classroom style and a project-based classroom in Europe versus America?
  - Undergraduate degree in 2009, so things might have changed.
  - They were in class all day everyday from 8-6pm. Each class was 2 hour periods and there was a 50 min lunch.
  - There was no quizzes or Homeworks nothing. Only a big final exam at the end that determined whether you passed or failed.
  - It is very independent and is very solitary. The exams can have written and oral where you are literally asked questions that you had to answer.
  - She prefers the US system. One of the main issues in Italy is that the higher education is free, there is also a high drop out rate too. Students are not supported.
  - Its also really hard to switch majors.
- Will we have to modify the project style to European classes, or can we use an American Style approach?
  - There is a difference in the approach that the students take. The students have more time outside of class to do homework.
  - Here we have a set amount of time we are expected to work each class. In Europe it is not like that. There may be resistant if the project has to be done outside of class without assistance. The project needs to be framed in a way they can see how they are improving and it needs to be valued by the faculty (I.e. getting a grade)
  - They need to be excited about it.
- Are the out of class expectations for schoolwork different between the two?
  - Studying is a guaranteed there. No one checks on what they do so each student does different amounts of work. There might be some resistance in doing group projects because other people are depending on you. Not used to groups so will need set guidelines.
  - Effective way to ease them into it:

        - Depends on the topic. And how much research and paper compared to lab based.
        - Using computer simulators to test ideas are still projects
        - If we were they are in a lab, there will be a huge learning curve for everyone.
        - Little Bits – can be used online to design things paired with a kit
            - Arduinos are part of the kit

- What is the typical workload per week for students in Europe?
    - Varies
- What kinds of homework are typically assigned?
    - No normal homework
    - Studying for final exam
- What is the grading style in Europe?
    - We won't get to pick what portion the project is worked. And teachers are sensitive about changing it
    - It Italy they are based on a scale of 30 were 30 is the best. 18 is passing. Grading is usually very harsh
    - Two averages between written and oral exams. It is actually typical to fail the exams a lot. You get 3 chances to retake the exam without having to retake the class.
        - Having no other assignments to base grades off of that is why they have multiple chances
    - 20-25% of the grade for the class final grade, assuming they also work outside of class. It would be easier to suggest this after the project is made, so this can just guide us now
- How can we best structure the module?
    - Need to make sure you have enough time the first week to explain what is going on. What he can do is have them meet an extra hour outside of lecture to work on projects and set it all up. Any set up HAS to be done early.
        - Its hard to decide the best format this early.
- What would they be more used to?
- Any more advice
    - Any possible language barrier. Need to consider whether or not they can do a project in English. We need to see if the goal is having an English portion. Keep our explanations simple. Have lots of links so they can better understand things.

Table 16: Major take-aways from interviews sorted by objective (Francesca Bernardi).

Major Take-Aways Sorted by Objectives		
Objective 1	**Objective 2**	**Objective 3**
Before creating a PBL for a college in Switzerland we need to understand what schooling is like there. When students start school in Italy, they pick their major at the beginning and stick with it. They only take classes related to the major. They will also spend Monday through Friday, 8-6pm in classes. Each class is 2 hours long with a 50-minute lunch. Grades are based entirely on your final exam, which includes a written and oral section. Final grade is the average between the two sections. Their grading scale of 30, where 30 is passing. Additionally higher education in Europe is free.	The topic that is picked can greatly affect what the project is and how you can format it.	When making the PBL you need to consider what the students are used to. In the US we have a certain expectation of the amount of time we will spend on a class. In Europe, that time is dependent on the students and how much time they want to put into studying. They are a lot more independent in Europe. When we make the project, it must be framed in a way that they can see themselves improving and have set deadlines. Most importantly the students need to be excited about the project. There also might be resistance to group projects because they are so used to being independent.
		If we have a hands-on component, we can use computer simulators paired with kits.
		We also should make the project worth doing (i.e., make it part of their grade). We won't get much say in this as professors in Europe are sensitive about changing grades.
		When we begin the project, we need to make sure there is plenty of time at the beginning to fully explain the project, and we need to have check in days to help the students. We can also add in lots of links so they can find answers on their own. There is always the chance of a language barrier, unless they are used to having an assignment completed in English.

7.8.4 Martin Gutsche

Key

Objective 1: Understanding PBL

Objective 2: Developing the topic

Objective 3: Creating the Module

Interviewers: Brandon, Joelynn, Chelsea
Interviewee: Martin Gutsche
Note Taker: Joelynn
Date: August 28, 2021
Time: 3:00 – 4:00pm EST
Location: Zoom
Interviewee has consented to have this interview recorded via zoom
Analyzed by: Chelsea

Questions and Notes

- *Have you considered incorporating projects into your classes? What has held you back from doing so up until now?*
  - They actually use it quite a bit. When they first enter in they do large groups and build robots that complete certain tasks.
  - There is projects in Microtechnology and there might have been some miscommunications about how things are at OST
- *How do you think adding a project to your course has affected your students' involvement/depth of knowledge in the course?*
  - There is both types available but not commonly mixed.
  - It is very important to have hands on projects. Only then you see how things work later on.
- *Have you employed any projects in your classes during your teaching career? If so, what format were they?*
  - There are specific lab courses. Very hands on. Have classes for etching and the certain process chain they run through. Has very specific time in clean room.
  - Would be nice to have specific time allocated to working things on paper before going to the clean room. Time is the biggest concern. How to allocate how much time is spent on each aspect.
  - It is frequently done to have prepared material that can then be processed by the students.
  - Virtual environment – virtual clean room to run the processes. Difficult to implement but maybe if done in small steps it can be accomplished. Maybe format it as an app that can simulate how things.
- *If you were to do group projects in your classes, how do you think it would affect student in class participation?*
  - Students do enjoy the hands on experience. But it is currently a separate course/ lab. The idea would be to include both lectures and labs into one course. It takes a lot of time to do the lab portion.
  - There are similar tools available that can be used in standard labs, but again a lot of cost that would have to be dedicated to just education purposes.
- *Do you think hands on experiences improve students' learning?*
  -
- *Can you think of what materials and equipment you may need to complete a project for your class? How accessible is this on a semester or year-to-year basis?*
  - Clean Room Processing

- One approach might be to have a bigger project in the background that multiple courses contribute to (linked to the project). Certain amount of time designated to the bigger project. Design the masks they would need for the processing sequence.
- Also include basic lecture material and then have separate time for building the device.
- Exercise or problem that is run on paper instead of the lab (more theory then practice).
- Their labs are just smaller versions of what is used int the real world. Wish that they had some sort of simulator.

- TinkerCAD might be an option for looking at sensors.
- We can do more research into finding virtual machines.
    - Microtech – process simulator, that has layers and include any information needed. And can process what the microchip can do. Unfortunately, expensive to buy the apps.
- *What is your preferred method of learning? Teaching?*
    - He is more involved with the lecture type of education. He is more involved with industrial projects and students at the master level. The projects are real devices and can even be something requested.
    - At a bachelor level more planned, but it is all still related to a real project and is more thesis type. This is at the end of their education for bachelor.
    - Right now it is separated between lectures and labs and it would be interesting to have more linkage. Have a project that is linked to all courses and is part of a greater project. Its not something done so far.
    - WPI has the linkage between courses. All classes have some sort of lab bases. (Brandon went into explanation of how things work here specifically with RBE)
- *When considering a potential project in your engineering classes, what do you think would be a reasonable length of time for the project to span? (3 weeks? 5 weeks? Etc.)*
    - Various scenarios available. Can be a set of three hour segment. Two hours of lecturing and then an additionally hour or problem based learning
    - Have certain sequences of lectures and then have a specific days for projects
    - The individual unit is 45 minutes long. 2 or 4 lectures per week. Semester is 14 weeks.
    - Have some time each week for problem based stuff
    - All this depends on topic.
- *Would you ever consider having a final project replace the final exam?*
    - Depends on the type of course and what they want to focus on especially with the different types of options. Do a final project half way through and then final exam at the end. Would have to consider the administration aspects.

Summaries by Objective:

Objective 1:

- *Have you employed any projects in your classes during your teaching career? If so, what format were they?*
    - There are specific lab courses. Very hands on. Have classes for etching and the certain process chain they run through. Has very specific time in clean room.
- *Can you think of what materials and equipment you may need to complete a project for your class? How accessible is this on a semester or year-to-year basis?*
    - Exercise or problem that is run on paper instead of the lab (more theory then practice).
- *What is your preferred method of learning? Teaching?*
    - He is more involved with the lecture type of education. He is more involved with industrial projects and students at the master level. The projects are real devices and can even be something requested.

Objective 2:

- *Can you think of what materials and equipment you may need to complete a project for your class? How accessible is this on a semester or year-to-year basis?*
    - Their labs are just smaller versions of what is used int the real world. Wish that they had some sort of simulator.
    - Microtech – process simulator, that has layers and include any information needed. And can process what the microchip can do. Unfortunately, expensive to buy the apps.

Objective 3:

- *If you were to do group projects in your classes, how do you think it would affect student in class participation?*
    - Students do enjoy the hands on experience. But it is currently a separate course/ lab. The idea would be to include both lectures and labs into one course. It takes a lot of time to do the lab portion.
- *Can you think of what materials and equipment you may need to complete a project for your class? How accessible is this on a semester or year-to-year basis?*
    - One approach might be to have a bigger project in the background that multiple courses contribute to (linked to the project). Certain amount of time designated to the bigger project. Design the masks they would need for the processing sequence.
    - Also include basic lecture material and then have separate time for building the device.
    - TinkerCAD might be an option for looking at sensors.
    - We can do more research into finding virtual machines.
- *What is your preferred method of learning? Teaching?*
    - Right now it is separated between lectures and labs and it would be interesting to have more linkage. Have a project that is linked to all courses and is part of a greater project. Its not something done so far.
- *When considering a potential project in your engineering classes, what do you think would be a reasonable length of time for the project to span? (3 weeks? 5 weeks? Etc.)*

  - Various scenarios available. Can be a set of three hour segment. Two hours of lecturing and then an additionally hour or problem based learning
  - Have certain sequences of lectures and then have a specific days for projects
  - The individual unit is 45 minutes long. 2 or 4 lectures per week. Semester is 14 weeks.
- *Would you ever consider having a final project replace the final exam?*
  - Do a final project half way through and then final exam at the end. Would have to consider the administration aspects.

7.8.5 Yarkin Doroz

Interviewers: Brandon, Evan, Joelynn, Chelsea
Interviewee: Yarkin Doroz
Note Takers: Joelynn and Chelsea
Date: August 30, 2021
Time: 9:00-10:00am
Location: Zoom
Interviewee has consented to have this interview recorded via zoom
Analyzed by: Chelsea

Key
Objective 1: Understanding PBL
Objective 2: Developing the topic
Objective 3: Creating the Module

Questions and Notes

- What was the hardest part about designing a project-based learning module?
  - For undergraduate courses there are a couple things to think about, you need to know who you are teaching. Students from various backgrounds are coming to the class. You need to find a balance of the tools they need to use. And know what kind of languages they are familiar with. Each student are more familiar with different languages then others, so you need to find a balance, so everyone learns. Finding the middle ground is hard.
- How has teaching your module changed over time?
  - Not much. He hasn't been teaching many years. He changes the course but not the project parts. Such as reducing the amount of homework. Things have had to change because of Covid. In terms of content things haven't changed, but the projects had to be altered to be able to do the project at home. He had to come up with a way to use breadboards so students can do the project at home.
  - Students tend to enjoy the projects. There are small changes to the projects through the years. The projects he uses are passed down from the past classes and he only made a couple changes. Schedules for undergraduates are very tight and its hard to make big changes.
- Have you made changes between the times you have taught it?
  - What were those changes?
  - What made you decide to change it?
  - COVID
- What style of projects work best with your class?
  - Several small projects?
  - Several small projects tend to be better.
  - He had taught a class before where it was only 3 large projects. For example if a student has problems with the first project they start to fall behind faster with less project options. So having a bunch of small ones lets them have time to learn what they did wrong at a better pace.
  - One large project?
  - This is only good if the students can keep up with the projects and don't fall behind. Sometimes if its not a project that builds up it gives them a chance to try something new instead of the same thing they struggled.
- Which one of your projects was your students' favorite?
  - In 2049 its an embedded course, they like to implement the small guitar hero game.

    - Its hard to determine what project they usually succeed with. Usually, the last one has the most completion. It depends on how much time they have to complete the projects.
- Any advice?
    - First to know your students and understanding the background they are coming from and they abilities.
    - He designed a graduate course. It can be more creative with less students, but with undergraduates there are more students and its harder to meet everyone's needs.

Summaries by Objective:

Objective 1:

- What was the hardest part about designing a project-based learning module?
    - For undergraduate courses there are a couple things to think about, you need to know who you are teaching. Students from various backgrounds are coming to the class. You need to find a balance of the tools they need to use. And know what kind of languages they are familiar with. Each student are more familiar with different languages then others, so you need to find a balance, so everyone learns. Finding the middle ground is hard.

Objective 2:

NTA

Objective 3:

- What style of projects work best with your class?
    - Several small projects tend to be better.

7.8.6 Gregory Lewin

Interviewers: Brandon, Joelynn, Chelsea
Interviewee: Greg Lewin
Note Takers: Joelynn and Chelsea
Date: August 30, 2021
Time: 9:00-10:00am
Location: IS 105 (Building on Campus)
Interviewee has consented to have this interview recorded via Voice Memos
Analyzed by: Chelsea

Key

Objective 1: Understanding PBL

Objective 2: Developing the topic

Objective 3: Creating the Module

Questions and Notes

- What was the hardest part about designing a project-based learning module?
  - Theoretical ideas are used in class and practice in Lab. The hardest part is the rapid fire of the system.
  - Figuring out how to line up hands on with lectures.
  - There will also be times where things don't line up properly between the two. You need to know what the overall goals are.
  - It's a design problem. Start off with what you want at the end and work out how it all fits together.
- How has teaching your module changed over time?
  - Students are the primary motivation of having things lined up. Some students don't enjoy having to learn things that don't immediately apply in class.
  - High Level vs. Low Level. Determining how much information to give. The big struggle is with a limited amount of time and deciding what is important.
  - There is always a bottom up approach. You can change objectives to meet the end goal. Most students see things from a bottom up approach and not top down. Students get overwhelmed a lot.
- Have you made changes between the times you have taught it?
  - The biggest things is looking at the final project. Lots of re-arranging things to fit better and changing their functionality.
  - You need to know your topic and how best to break it down by the steps that need to happen.
  - If someone falls behind they have their team as support. The students help each other first and work together is someone falls behind. It helps them build life skills. Falling behind is part of work and this helps them work better in the future.
  - Having things flowing together is better than weeks of lecture and then suddenly the project.
- What style of projects work best with your class? Which one of your projects was your students' favorite?
  - Each week if they have something to show and knowing that it will help with the end goal helps students want to learn the material.
  - Learning things and then applying the information.
- Any advice?
  - Starting with writing the objectives. Knowing what we want and working backwards from the final project/ end goal.

- Always keep track of the objectives and work backwards.
- "Robotics is about how you integrate all this stuff together"
- Keep the big picture items in mind.
- Be critical of things you are covering. Are they realistic or possible? Embrace the freedom of starting from scratch.

Summaries by Objective:

Objective 1:

- What was the hardest part about designing a project-based learning module?
  - Theoretical ideas are used in class and practice in Lab. The hardest part is the rapid fire of the system.
- How has teaching your module changed over time?
  - Students are the primary motivation of having things lined up. Some students don't enjoy having to learn things that don't immediately apply in class.
  - High Level vs. Low Level. Determining how much information to give. The big struggle is with a limited amount of time and deciding what is important.
- Have you made changes between the times you have taught it?
  - The biggest things is looking at the final project. Lots of re-arranging things to fit better and changing their functionality.

Objective 2:

NTA

Objective 3:

- What was the hardest part about designing a project-based learning module?
  - Figuring out how to line up hands on with lectures.
  - It's a design problem. Start off with what you want at the end and work out how it all fits together.
- How has teaching your module changed over time?
  - There is always a bottom up approach. You can change objectives to meet the end goal. Most students see things from a bottom up approach and not top down.
- Have you made changes between the times you have taught it?
  - You need to know your topic and how best to break it down by the steps that need to happen.
  - Having things flowing together is better than weeks of lecture and then suddenly the project.
- Any advice?
  - Starting with writing the objectives. Knowing what we want and working backwards from the final project/ end goal.
  - Always keep track of the objectives and work backwards.
  - Be critical of things you are covering. Are they realistic or possible? Embrace the freedom of starting from scratch.

7.9 Appendix I: AFM Project Rubric

Table 17: AFM Project Rubric deliverable.

Topic	Exceeded Standards	Met Standard	Needs Improvement	Total Points
Presentation Skills				
Public Speaking	When presenting students have good eye contact with the audience and do not read directly off the slides. Students also do not use filler words.	When presenting students typically have good eye contact with the audience but do occasionally read directly off the slides. They use some filler words.	Students do not have good eye contact and read directly off the slides. They frequently use filler words.	____/0.5
Teamwork	Same as met standards and including "handing off' between slides.	Students equally present the data needed and no one is talking too much or not enough. They also do not talk over each other.	Students do not present the data equally and there is an uneven balance in contribution. Students also frequently talk over each other.	____/0.5
Content				
Background	Shows thorough research with sources and an exceptional understanding of the AFM probe.	Has research but does not fully convey what was learned. There are some sources, but they are not always made clear.	Poorly done research that doesn't support what was stated. Has little to no sources. Does not show a clear understanding of AFM probes.	____/0.5
Applications of Probe	Clearly states an in-depth application of the probe.	States an application of the probe.	Does not explain or state an application of the probe.	____/0.5
Engineering Procedures	Clear, succinct, well thought out.	Mostly explains the process, but some things are still unclear.	Does not explain or state engineering procedures.	____/1.0
Calculations	Shows a clear process of what equations were used and how they support the data shown.	Has some calculations but does not fully explain the context.	Shows little to no calculations with no context.	____/1.0
Challenges	States/explains challenges encountered and elaborates on how they were overcome.	States/explains challenges encountered during the project.	Does not state or elaborate on challenges encountered.	____/1.0
Prototype the Probe				____/1.0
Knowledge of Topic				
Q&A	Shows confident understanding of material, can answer most, if not all, questions.	Shows moderate understanding of material, can answer majority of questions.	Shows limited understanding of material. Can answer a few questions, but it is not answered clearly.	____/2.0
Final Project				
AFM Prototype				____/2.0
Final Grade:				___/10

7.10 Appendix J: AFM Project Timeline

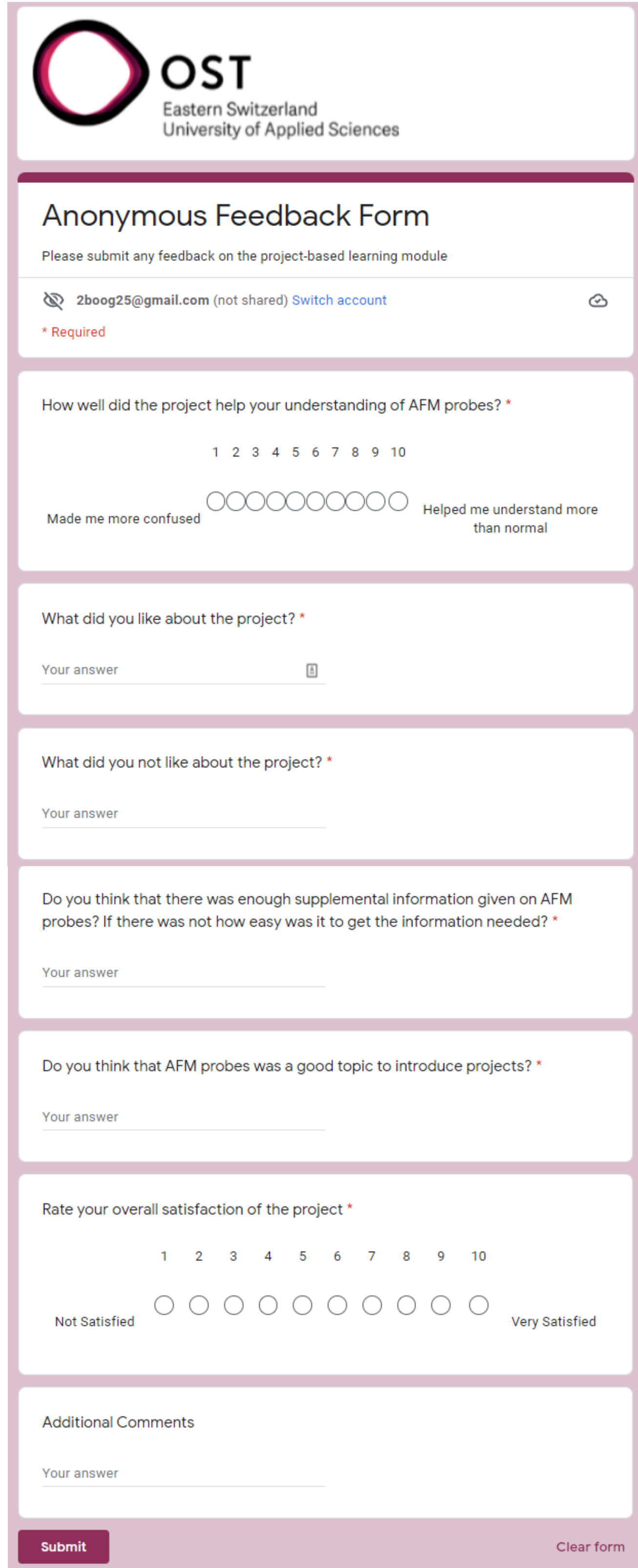
Table 18: Project timeline deliverable.

	Class Time
Week 0	Introduction to project-based learning
Week 1	Introduce the project to the students and break students into groups Begin teaching AFM to students Be sure to start covering equations needed for the probes
Week 2	Check in with students on their math/ revisit equations if needed Preliminary Design Review Presentations due by Friday
Week 3	Check in with students and make sure they have their procedures completed and designs finalized Groups that are ready can begin the manufacturing process Students should work on the applications of their probes and PowerPoint in general
Week 4	Check in with students to see how their prototypes are going Critical Design Review Presentations due by Friday and will present during the next class

7.11 Appendix K: Post-Project Survey

Questions for OST students after completing the PBL module:

- How well did the project help your understanding of AFM probes?
    - Rate on a scale of 0 to 10
    - 0 = made me more confused
    - 5 = same as a lecture
    - 10 = helped me understand it way more than normal
- What did you like about the project?
- What did you not like about the project?
- Do you think that there was enough supplemental information given on AFM probes?
    - If there was not how easy was it to get the information needed?
- Do you think that AFM probes was a good topic to introduce projects?
- Rate your overall satisfaction of the project
    - Rate on a scale of 1 to 10
    - 1 = not satisfied
    - 10 = very satisfied



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Anonymous Feedback Form

Please submit any feedback on the project-based learning module

2boog25@gmail.com (not shared) Switch account

* Required

How well did the project help your understanding of AFM probes? *

1 2 3 4 5 6 7 8 9 10

Made me more confused — Helped me understand more than normal

What did you like about the project? *

Your answer

What did you not like about the project? *

Your answer

Do you think that there was enough supplemental information given on AFM probes? If there was not how easy was it to get the information needed? *

Your answer

Do you think that AFM probes was a good topic to introduce projects? *

Your answer

Rate your overall satisfaction of the project *

1 2 3 4 5 6 7 8 9 10

Not Satisfied — Very Satisfied

Additional Comments

Your answer

Submit

Clear form

Sample survey done on Google Forms