Plug-n-Play: A Flexible Approach to Active Learning

Dr. Wei Wu, Berea College

Dr. Wei Wu is currently an Assistant Professor in the Department of Engineering Technologies and Applied Design at Berea College. She received her Ph.D. in Engineering Science with a concentration in Electrical Engineering from the Southern Illinois University Carbondale in 2017. Her research interests include renewable energy technology, power electronics, and designing sensor nodes for coral reef restoration. She is also interested in Engineering education and is willing to try different pedagogies to help her students learn electronics.

Scott Heggen, Berea College

Dr. Scott Heggen serves as an Associate Professor of Computer Science and Chair of the Computer Science department at Berea College. Much of Dr. Heggen's interests have focused on embedded systems, in particular, how can Arduino, Raspberry Pi, and similar embedded computing devices, coupled with sensors and logic, be used in socially-aware and socially-relevant contexts. Dr. Heggen also leads the Student Software Development Team, a cohort of labor students who are hired through the Berea College Labor Program to develop software solutions to support various departments on campus. The software team is responsible for the entire software engineering lifecycle, from initial design and customer requirements gathering to software maintenance and upgrading as new features and bugs are identified. Started in 2014, the team now maintains 9 software systems, with new systems being developed and maintained each year. Finally, Dr. Heggen is always seeking ways in which we can broaden participation in computing to underrepresented populations, helping ensure future technologies support and represent all people.

Emmaley Clare Powell
Oussema Khlifi
Trayvion Jalan Newton

Plug -n- Play: A Flexible Approach to Implementing a Dynamic Active Learning Classroom

Abstract

Educators tend to build their courses based on their preferred teaching style, but that teaching style often does not align with the needs of the class or take into consideration the changing nature of their student demographics. Furthermore, new educators are often encouraged to use an active learning pedagogy, particularly in STEM fields, where students learn best by constructing their own knowledge about a particular subject, but these instructors may have no prior experience in implementing these strategies effectively.

This paper is centered around lessons learnt in the implementation of an introductory electricity and electronics class, which covers various topics including: fundamentals concepts such as voltage, current and Ohm's Law; use of mathematical skills to solve circuits; hands-on exercises, such as breadboarding circuits; PCB design, fabrication, and soldering; and Arduino programming fundamentals. The class is open to all students at the institution, resulting in a highly diverse population, both in class rank and identity. Any given class will have a mixture of seniors through first-years. Students have typical majors such as Engineering Technology, Computer Science, Engineering, but also atypical majors find value in the course as well, such as Communications, Education Studies, Theater, and others. This wide range of student identities, experience, and academic focus result in very diverse classrooms, which is atypical in engineering, engineering technology or computer science programs.

To teach such a diverse range of students, we developed the Plug -n- Play approach, a flexible pedagogical approach which ensures instructors have a fixed core structure, flexibility in leveraging their own teaching style, and a mechanism for constant reflection which allows for adaptations to the course structure over time. The PNP approach focuses course design around the student experience, while acknowledging and supporting individual teaching styles and teaching methods.

To assess PNP, a classroom observation protocol was developed to evaluate student engagement, as well as examination of sixteen sections worth of grades and student evaluations. The results show that students are highly engaged with the course material, peers in the class, and the instructors. Finally, the PNP approach supports students in building self-efficacy in their abilities as electricity and electronics students.

Introduction

Active learning is a teaching pedagogy which has gained traction in higher education as an effective method for engaging learners in the process of attaining new knowledge [1]. It moves the student from a passive role in hearing and absorbing information, to an active participant in constructing new knowledge, typically through hands-on exercises. Active learning is an umbrella term used to describe many different types of practices, including role playing activities, pair programming, project-based learning, and many others [2].

Many introductory electricity and electronics courses are ripe for this type of teaching as many of the topics can be learnt through interacting with electrical circuits and other hardware and software [3][4]. For example, instead of an instructor lecturing through the math of calculating a circuit, students can construct the circuit themselves, measure the circuit using a digital multimeter, then answer guided questions about their observations. Unlike a lecture, it becomes difficult for the student to disengage with the content and it frees the instructor to be able to intervene directly with the student if they do become disengaged or are struggling to understand the material.

The challenge then becomes selecting the appropriate type of active learning to use in the course given the wealth of different options. For new instructors, professional development (e.g., workshops or conferences) plus having a mentor who understands active learning pedagogy well can help them select between the myriad of choices. Developing a teaching style becomes critical to their success in the first few years of teaching. For experienced instructors, changing their teaching practice can represent significant work, as it may mean a complete rebuild of the course structure and materials. Either way, implementing new active learning in an effective way takes good mentorship, years of practice, and lots of trial and error [5].

Furthermore, different active learning styles will suit students differently based on their personality, learning styles, and prior experiences in education and the subject. For example, our introductory course for electricity and electronics in Fall 2021 was 90% seniors and juniors, while our current Spring 2024 cohort is nearly 50% sophomores. A pedagogical approach that expects students to be able to do more individualized work, such as a flipped classroom approach, might not work as well for the latter cohort, given that on average, sophomore's study skills may be less developed than the juniors and seniors.

Plug -n- Play (PNP) presents a divergence from treating any single active learning strategy as a solution to effective teaching. Instead, we present an approach to designing a course which examines the learning goal of a class session, multi-class module, or an entire course, and encourages selection of the appropriate active learning strategy to achieve that goal. The flexibility provided by PNP alleviates the challenges faced by faculty, new and experienced, in implementing active learning strategies that may not yet be deeply understood.

For example, Process-oriented guided inquiry learning (POGIL) [6] is an active learning technique to facilitate in-class learning which relies on timed guided activities, assigned roles, small group discussion, and Socratic-method discussions between the instructor and the class. To implement POGIL well, workshops and other professional development activities are encouraged, and it still may take years to effectively use POGIL. Alternatively, the usage of POGIL strategies that aligned with the course learning goals (i.e., guided activities with small group discussion) were carefully selected, while other practices (e.g., assigned roles), while valuable in some contexts, did not align with our learning goals; instead, ideas from pair programming [7], another active learning strategy, were used to encourage collaboration. In a way, PNP allows the instructor to slowly adopt good practices that current research shows are effective, without committing to a complete overhaul in their teaching style and practice.

The remainder of this paper is organized as follows: first, an overview of the introductory electricity and electronics course structure, informed by PNP, is provided. Next, the PNP approach is presented, followed by more details on how PNP was implemented in the course. Next, an evaluation of PNP is given, first looking at observations about student engagement, followed by course evaluation data related to the effectiveness of PNP in learning effectiveness and self-efficacy. Final thoughts are then provided in the conclusion.

Course Background

The PNP approach centers around a course that serves as an introduction to electrical concepts for students who have no previous electronics experience. The open enrollment policy of this course results in a mixture of first-years to seniors, and majors and non-majors, resulting in diverse rosters each time the class is offered. For students majoring in Engineering Technology, Computer Science and Engineering, this course is an introduction-level course that lays a foundation of electricity and electronics concepts that will often lead to future classes in their majors. For non-major students, such as biology, music, or theater students, the course satisfies general education requirements; this may be their only electricity and electronic course in their entire academic career.

In the course's design starting back in 2017, topics were selected to cater to the needs of all students. The class was structured around four main themes, as outlined in Table 1.

Table 1: Course themes and subtopics

Theme	**Subjects**
Foundational Concepts	Basic Concepts of Electricity
	Multimeter, Breadboard and Power supply
	Safety
	Ohm's Law and Power
	Series, Parallel, Combo Circuits
Prototype to Production	PCB Schematics and Layouts
	Integrated circuit and other discrete components
	PCB Milling and Soldering
Software and Hardware Interaction	Arduino Board Hardware
	Arduino Programming Syntax
	Sensors and Motor control
Final Project	

In these four themes, the varied nature of the learning goals is apparent; foundational concepts delve into the algebra to understand circuits; prototype to production leans more heavily into hands-on activity to construct a physical electronic device; software and hardware integration bridges the digital and physical worlds of electronics; and the final project ties these areas together to explore new ways of constructing electronics.

Based on these themes, our objective was to design a course that incorporates hands-on and project-based activities. Taking into consideration our students' diverse backgrounds, we aimed to craft a course structure that promotes an equitable learning experience for all by engaging them in an adaptable learning process and offer rich support to those who may be struggling with the content. We liked the idea of use flipped classroom to develop independent learning skills and have more time working on hands-on activities in class. We like the idea of POGIL's guided inquiry materials and small group concept. We also valued traditional lecture and demonstrations. Nevertheless, we recognize that these approaches may not adequately accommodate students with varying learning paces and diverse backgrounds. Hence, we designed the PNP approach to achieve our goals through a fixed core structure with intentional flexibility.

The Plug -n- Play Approach

We identified three goals when developing the course:

1. **Inclusive content delivery:** With a mixture of student identities, the course must be designed to ensure the effective delivery of targeted content to all students, regardless of their backgrounds. This requires flexibility, allowing instructors to employ various strategies and accommodate different learning styles.
2. **Fostering a healthy learning community:** A healthy learning community is one where all students feel supported in their learning journey. The course structure should allow instructors to quickly identify students who are facing challenges and provide them with extra support when and where it is most needed. The course should also support peer collaboration and learning form a sense of belonging. Individualized support and peer interaction encourages students to seek assistance whenever necessary, whether from their peers or instructors.
3. **Flexibility in teaching styles:** Instructors need to be able to choose their own teaching style when delivering content. This flexibility recognizes that every instructor has different strengths in their approach to teaching. The PNP approach can incorporate a range of teaching methods, from traditional lectures to the newest active learning pedagogues. It is intended to meet the instructor where they are at in their journey to effective teaching.

The PNP approach draws inspiration from various active learning pedagogues. It is designed with three main components that align with the goals above: first, it requires a fixed core structure that provides students with consistency from class to class. Second, PNP grants instructors the freedom to implement the fixed core structure by bringing their own teaching style into the classroom; we define this as a flexible teaching approach. Finally, successful implementation requires consistent assessment of student performance, prompting instructors to reflect on and modify their methods and assignments regularly. We will discuss these three components in detail.

The fixed core structure: The fixed core structure provides students with a known, repetitive structure that the students can anchor their learning around. In our course, the fixed core structure has a weekly rhythm. It begins with students previewing the course material before class. The students are assigned readings or videos that concentrate on abstract concepts. For example, a short video and reading article are used to explain voltage and current. It's important to note that in our PNP approach, the expectation is not for students to master the entire course content outside the classroom.

Then, a short quiz is administrated at the beginning of class. This quiz provides an opportunity for students to discuss their understanding of the reading. It is intended to be a low-stakes evaluation of the student's comprehension of the material. Reviewing the quiz questions in class becomes a valuable teaching moment in the PNP approach, allowing students to asking questions through discussion, fostering a collaborative and interactive learning environment.

Following the quiz, students spend the rest of time dedicated to in-class activities that are designed to delve deeper into the day's content. These activities incorporate hands-on activities followed by guided questions and small lecture notes. The guided questions require students to observe the results of their actions, respond to reflective questions, and discuss their observations with a partner. This intentional design aims to promote students engagement and encourages them to ask questions about the course content in an active learning environment.

As students actively navigate these guided questions at their own pace, instructors move around the class to provide assistance as needed, offering support or rotating among tables to gauge students' progress. This dynamic interaction ensures that the classroom becomes a space not only for content delivery but also for personalized assistance and collaborative exploration of the subject matter.

At the end of each assignment, the fixed core structure requires instructors to recap the activity and check for understanding. It is a crucial step to address any potential misunderstandings.

Flexible teaching: Within the context of the fixed core structure, instructors can utilize a variety of pedagogical methods that align with their strengths and resonate with the class. This might involve traditional lecture, interactive discussions, real-life storytelling, or hands-on demonstrations, creating a dynamic and engaging learning environment that leverages the instructor's strengths. For example, instructors can choose to provide a class demonstration at the beginning of class, or deliver mini-lectures throughout a class activity to reinforce specific content. While the fixed core structure provides students with stability, the flexible teaching provides the instructor with the ability to adapt to the exact needs of the class.

This flexibility extends to how instructors provide individualized support and promote an equitable learning environment. Whether through personalized one-on-one sessions, small group discussions, or supplementary materials, instructors can tailor their support strategies to address individual student needs effectively.

Flexibility can be implemented at multiple stages of designing the course. For example, prior to day one, the instructor may choose a POGIL-based fixed core structure for in-class content delivery. However, when the class gets to the soldering activity, POGIL is no longer the most effective way to engage the class, so the instructor can switch to a traditional lab-based approach, where the students work individually to solder their own PCB, but move together at the same pace. In the middle of the assignment, the instructor may notice multiple students soldering a component incorrectly, and pause the class for an in-class demo. Because the PNP has flexibility baked into its framework, the instructor can adapt quickly to the needs of the class at any given moment.

Constant reflection: PNP requires instructors to reflect on their teaching methods, regularly assess students' performance, and adapt assignments and activities accordingly. This iterative process ensures a continuous improvement in the effectiveness of the course structure within a single class, as well as between terms.

Instructors are required to routinely review and interpret student responses to guided questions, quizzes, and observations of in-class performance. For example, the brief quiz discussion is an excellent in-class assessment point to evaluate students' prior knowledge and their outside learning through quiz discussions. Similarly, in the recap section, instructors can ask the class to "describe the most challenging part of this assignment, and why it was challenging." Instructors are also encouraged to reflect on the impact of their chosen teaching styles, the effectiveness of class activities, and the overall engagement level of students. This constant reflection allows instructors to have the opportunity to modify content delivery methods, optimizing the balance between fixed and flexible elements within the PNP structure, adjust the length of activities, modify the difficulty level of the guided questions, and tailor support mechanisms based on the observed progress of individual students and the class as a whole. This constant reflection is particularly important for classes with diverse students background as it ensures the instructor is more aware of their own biases while teaching.

Overall, PNP allows the instructor of a course to provide a consistent structure to the students' learning process while simultaneously giving the instructor the flexibility to adapt the way the students engage with the course content as the course progresses. The PNP approach empowers the instructor to choose the appropriate active learning pedagogy that aligns with the learning goal at any moment of time in the course: prior to day one when it is still being developed, at the thematic level, at the subject level, and even at the individual class level.

Implementation of Plug -n- Play

In this section, we will discuss how PNP was implemented in our introduction of electricity and electronics class. Samples of the course plan and activities will be discussed. Class observations were conducted to assess students engagement in our class during the Fall 2023 semester. The setup and results of those observations will be presented in the next sections.

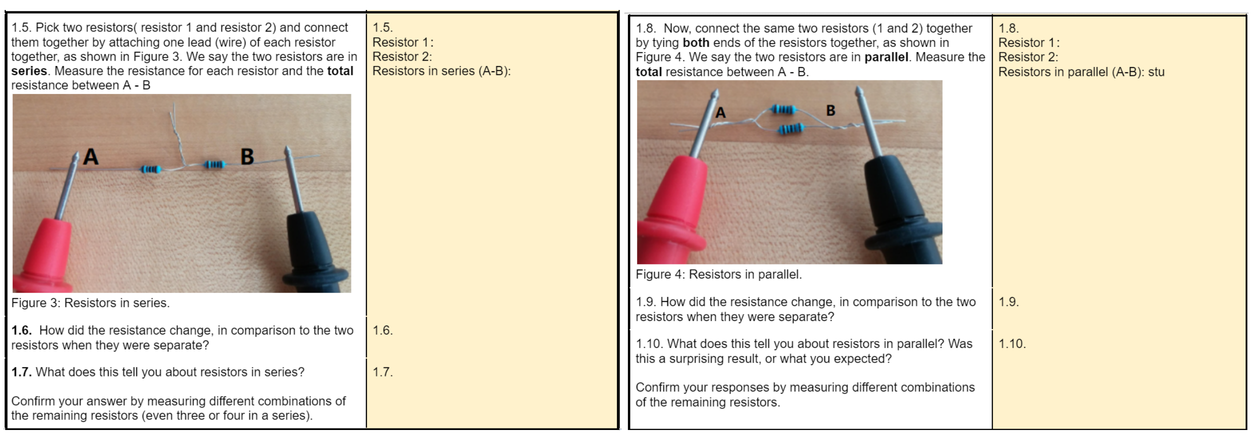
I. Selecting the fixed core structure

The fixed core structure in our PNP implementation was a guided hands-on activity for each class session. To accommodate varied learning paces and ensure all students could complete the content, we assigned two class periods (equivalent to 4 hours) for each in-class activity. The activities were named teamworks because they require students to work in pairs. The term teamwork will be used to refer to these in-class activities moving forward.

A range of reading materials were selected for our pre-class quizzes, including textbook readings, demonstration videos, and the instructors' own notes. Since each teamwork session spans two class periods, a group quiz involving short discussions is conducted during the first class period to check the students' understanding of the material. This prepared them for starting the teamwork activity. In the second class period, we opted for a review quiz in order to assess their understanding of the previous teamwork they had just completed, as a way of assessing if the learning was being retained beyond the two class periods.

Our implementation of PNP also used pair programming (i.e., driver and navigator) [7] in the teamwork activities. The navigator would read the document, provide the driver with instructions on what to do, and record responses to questions. The driver would do the physical operation (i.e. building the breadboard and taking measurement). Following pair programming, the driver and navigator are expected to switch roles regularly, so both students are engaging with the material equally. By emphasizing both a written and hands-on exam will be coming later in the semester, students stay motivated to switch roles often. Students will build circuits, solder components, and reflect of what they have learned through the guided questions or tasks. An excerpt of the very first class activity is given in Figure1.

In this activity, most students have never seen a resistor or used a multimeter before. We asked students to use a multimeter to measure the resistance of series or parallel resistors first, then we ask students to think critically about their finding. Many students become curious to understand why parallel resistors have less total resistance, and inquire a response from the instructor and TAs. Despite this activity's simplicity, it lays a foundation for series and parallel circuits which students explore in more detail in a future class period.



1.5. Pick two resistors(resistor 1 and resistor 2) and connect them together by attaching one lead (wire) of each resistor together, as shown in Figure 3. We say the two resistors are in **series**. Measure the resistance for each resistor and the **total** resistance between A - B Figure 3: Resistors in series.	1.5. Resistor 1: Resistor 2: Resistors in series (A-B):
1.6. How did the resistance change, in comparison to the two resistors when they were separate?	1.6.
1.7. What does this tell you about resistors in series? Confirm your answer by measuring different combinations of the remaining resistors (even three or four in a series).	1.7.

1.8. Now, connect the same two resistors (1 and 2) together by tying **both** ends of the resistors together, as shown in Figure 4. We say the two resistors are in **parallel**. Measure the **total** resistance between A - B. Figure 4: Resistors in parallel.	1.8. Resistor 1: Resistor 2: Resistors in parallel (A-B): stu
1.9. How did the resistance change, in comparison to the two resistors when they were separate?	1.9.
1.10. What does this tell you about resistors in parallel? Was this a surprising result, or what you expected? Confirm your responses by measuring different combinations of the remaining resistors.	1.10.

Figure 1: First Class Teamwork Activity Sample

Because all students work at a different pace, some students finish teamwork assignments early. They are encouraged to become peer mentors and help other students. The course structure enables instructors or TAs to provide additional support to those falling behind, fostering equitable in-class learning, and helps the class better identify as a learning community. Finally, for students who face significant challenges in finishing the assignment on time, TAs host an optional tutoring session outside of class to help them catch up on the material.

II. Implementing the flexible teaching strategy

Since 2018, this course has been taught by two faculty members, and there are typically two sections per term. Instructor A identifies as a male Associate Professor with a background in computer science. Instructor B identifies as a female Assistant Professor with a background in Electrical Engineering. For simplicity, we will refer to Instructor A's class as section A, and section B for Instructor B. Through bi-weekly meetings between the two faculty members, both sections are kept in sync throughout the term. However, leveraging the flexibility offered by PNP, each faculty member can adopt their own teaching style or implement common active learning approaches based on their teaching strengths and observations of the classes.

For example, following Teplitski et al [8] and Aflalo [9], both faculty members implemented a pre-exam, question writing activity. Students worked in small groups to review course content and develop questions, which are shared among all students. This became a review sheet for the students to use as they prepared for the exam. The instructors then wrote the exam using the students' questions as a foundation for understanding where the students are in the learning process. Research has shown this reduces exam anxiety, encourages team collaboration while studying, and fosters a learning community.

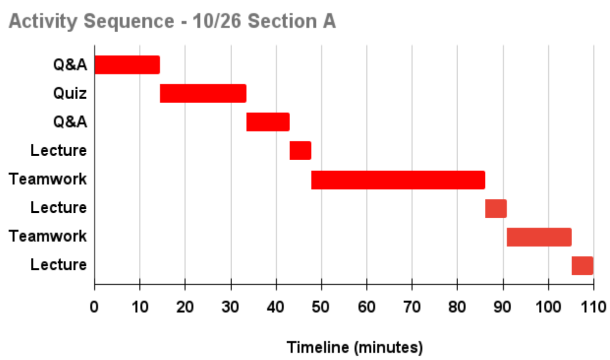
In the final project phase, both instructors choose to incorporate ideas from project-based learning [10] as the base active learning pedagogy. A teamwork assignment serves as the core structure to guide students through various stages, including developing a project proposal, creating a breadboard prototype, producing the final product, and preparing for the final demonstration.

While both instructors have opted for some common active learning approaches, each instructor has the flexibility to choose other active learning methods that best suit their individual teaching style. In Fall 2023, an observer attended multiple classes in both sections and was able to evaluate both instructors' teaching style and how they implemented PNP. The observer noted the following which highlights the flexible nature of PNP:

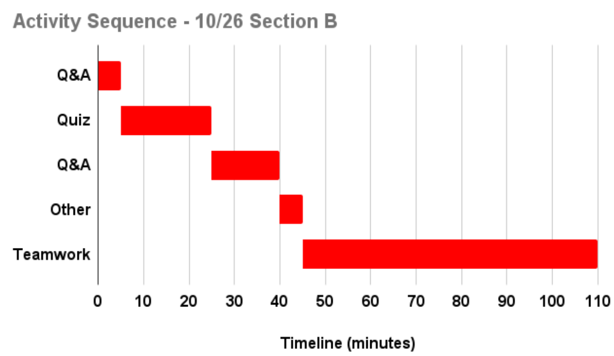
> "At the beginning of class, both professors thoroughly answer students' questions about the readings or material before a quiz. Instructor A gives the individual part of the quiz first, with the group section after, and includes both in the final grade of the quiz. Instructor B gives the group quiz, which goes ungraded first, followed by a graded individual quiz. After the quiz, if new material was introduced that day, Instructor A would normally give an overview of the information needed to start the teamwork but leave more of the little things up to the students to learn through the hands-on experience while working together. If something becomes a common issue or question among the students while working, Instructor A will stop the class and offer a short lecture about what was troubling them. Instructor B takes more of a preventative approach and goes further in-depth about the important information, as well as the activities within the teamwork during the lectures before the students start

working. Both professors will then roam around the room to make sure the students are actively making progress in the teamwork and answer any questions that arise."

Figure 2 presents observation data for a specific class held on October 26, 2023 which also highlights the dynamic teaching style of each instructor. Instructor A incorporated multiple small lectures throughout the course, responding to low engagement because section A was at 8:00 AM. Instructor B chose to jump straight into the teamwork due to strong quiz performance. Instructor B leveraged the extra time to adjust the groups due to several under-performing teams in the previous lesson, as indicated by the "Other" activity in the figure.



(a) Activity Time Sequence for Section A



(b) Activity Time Sequence for Section B

Figure 2: Course Sequence Comparison between Two Instructors

III. Evaluating through constant reflection

Constant reflection allows the instructors to improve the class at multiple intervals. For example, a key teaching objective is to ensure students can construct a breadboard and proficiently use appropriate measurement equipment. In 2018 and 2019, the pass rate for this skill in hands-on exam assessments was only slightly above 70%. In response, the instructors developed a better teaching approach for breadboarding by asking the students to explore the internal connections inside a breadboard using a continuity tester. Additionally, the mapping node method was introduced, requiring students to identify common connection points in a schematic and mapping those nodes to the breadboard's internal connections. As a result of these two changes, the pass rate for the same hands-on exam has since increased to 90%.

The instructors and TAs have weekly meetings to review assignments, reflect on their section's performance, and modify assignments if necessary. For example, it was observed that students faced a significant challenge with the PCB design assignment. Mastering PCB layout software, particularly in an introductory-level class, was proving challenging to do in a single week. To address this, the PCB tasks were redistributed across multiple existing homework assignments. In the first homework, students install and learn to do basic manipulations in the EAGLE PCB software. By week four, they are auto-routing basic PCBs. By the time students engaged in the teamwork to prototype an audio amplifier, including cutting a PCB on a circuit mill, they had already engaged with the skills necessary to draw schematics and layouts in Eagle.

Course Engagement

Peer interaction is crucial in forming a robust learning community in the classroom. Through collaboration, discussion, and shared learning experiences, students can constructively engage with their peers, exchange ideas, and deepen their understanding of course material. Moreover, peer interaction cultivates an inclusive and supportive learning environment where students feel confident to seek assistance. To study students' peer interaction and engagement in the class while using the PNP approach, we developed an observation protocol to directly observe students' engagement across multiple dimensions. The protocol allowed us to systematically examine participation in the course, facilitating ongoing assessment and refinement of our course materials. This section will focus on the observation protocol and what it has revealed about two sections of the the Fall 2023 classes.

The observer protocol we deployed drew inspiration from multiple existing protocols [11][12][13][14][15][16], and it was designed to fit in our classroom setting. The protocol aims to determine how students are engaged (or not) during class time. Therefore, in our protocol, we focused the protocol on observing the classroom activity (i.e., what was happening in the class) and the student's engagement type (i.e., how was the student engaged with that activity).

Similar to (FASTOP) [13], five different types of student engagement were identified, detailed in Appendix A. The teamwork assignments have guided questions and tasks designed to engage the student at various cognition levels following the revised Bloom's Taxonomy [17]. Since students process those tasks and questions at their own pace, we were not interested in knowing student's cognition level during observation. Instead, we considered a student engaged as long as they were working on the activity, whether they were working on course materials (M), listen to the instructor (I), discussing with their partner (P), or helping other students in class (C), students were considered engaged with course material. All other activities (e.g., checking their phone, going to the bathroom, looking at non-course materials) are considered as Disengaged (D).

The different course activities, also described in Appendix A, were used to understand what activity was being conducted when the students were in each state of engagement above. Given the wealth of active learning pedagogues presented and an interest in moving away from claiming any active learning pedagogy as a single "right" choice, the specific pedagogy being used is not included in our protocol. Instead, we lumped the course activities into larger, more generic categories which are well-known to have different levels of engagement [18]. For example, to explain electrical safety, an instructor may conduct a traditional lecture, do a role-playing activity, tell a story, or conduct a live demonstration. All of these activities fall into the lecture category because the emphasis is on the instructor conveying information to passive listeners. Alternatively, we categorized Q&A sessions differently due to their interactive nature; students posed questions to the instructor, who then answered the question, which often led to new questions and discussion.

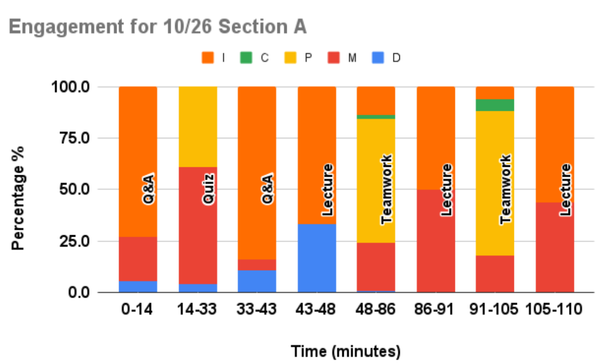
In Fall 2023, three observers used the protocol in both sections for ten different class sessions, representing the five different teamwork assignments. These ten sessions reflect the course themes described by Table 1: circuit analysis for combination circuits, debugging and soldering PCB boards, introductory Arduino programming and sensors, use of an Arduino and motor controller to control a Robotic Car, and the final project. Section A had a total of 14 students, and section B had 20 students.

Figure 3 presents the observer data during one session, the introductory Arduino programming teamwork. The matching activity time sequence is provided above in Figure 2. Our goal was to understand how different class activities related to student engagement.

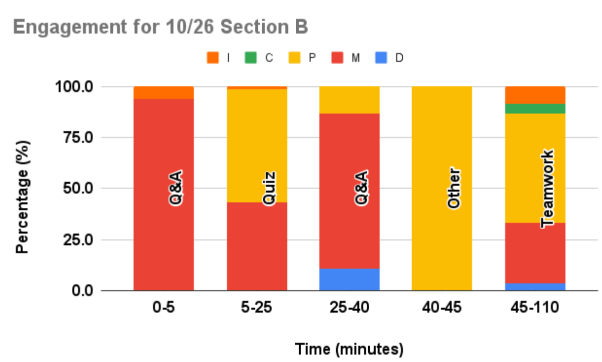
Multiple interesting observations can be concluded from the data. For instance, in section A three mini-lectures were used; in all three cases, around 50% of the class was focused on the instructor (I), while the rest were focused on material (M) or distracted (D), aligning with most claims about the effectiveness of lectures compared to active learning. In section B, both Q&A sessions appear to be used by the class to focus on the material, indicating those students placed more value on reading than interacting with the instructor; section A was the exact opposite, with over 75% of the class engaged with the instructor during Q&A.

Surprisingly, some of the highest disengagement happened during Q&A. Upon reflection, one possible explanation is the types of questions being asked during Q&A. For instance, a student asking a very difficult to understand question will disengage other students because they are lost. Alternatively, a very simple question might have a similar effect, because other students already know the answer. More generally, Q&A sessions might engage a small subset of the class well, but it can also leave the remaining students disinterested, leading to disengagement.

Another conclusion we can draw from both sections is the effectiveness of the teamwork in engaging the students; almost no students are distracted during those sessions, despite teamwork representing the majority of the time in class (on average almost 60 minutes of the 110 minute classes).



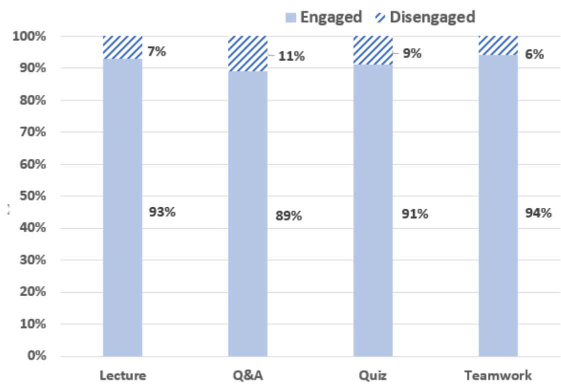
(a) Engagement Type for Section A



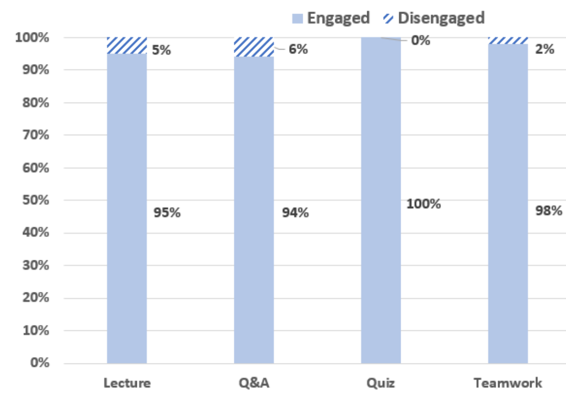
(b) Engagement Type for Section B

Figure 3: Course sequence comparison between two different instructors

Finally, a goal of the instructors was to the formation of a learning community, were students feel comfortable asking questions to their peers and other students across the classroom. In both sections, we see a significant amount of the class time was spent in engaging with their partner (P) or classmates (C), indicating a healthy learning community exists in this class session.



(a) Section A



(b) Section B

Figure 4: Overall Students Engagement Level per Course Activity

While figure 3 shows engagement across a single class session, figure 4 shows the tallied total engagement levels across each broad activity type. We considered students engaged as long as they were reading assignment material (M), interacting with the instructor or TA (I), discussing with partners (P), and helping other classmates (C); otherwise, they were considered disengaged (D). Overall, both sections were highly engaged throughout the 110 minute classes, with section B being slightly higher than section A. One likely explanation is that Section A was at 8:00 am and section B was at 10:00 am. It also explains the increased disengagement during Q&A time in section A, which happens at the beginning of class. Generally speaking, students were more engaged in later morning classes, but both sections remained highly engaged overall. Future offerings of the class will reveal if the class offering time had the observed disengagement effect.

In summary, our analysis leads us to assert that students exhibit a high level of engagement with the course content as a response to the PNP approach. The flexible teaching style of PNP provided the instructors with the ability to bring their own strengths to the class, and adapt their teaching to the needs of the class in situ. The prevalent engagement, particularly during teamwork activities, highlights the active participation of students in the learning process and the formation of a healthy learning community.

Evaluate Teaching Effectiveness

In addition to engagement, we aim to explore if our teaching style supports an effective learning environment for students from diverse backgrounds and contributes to building self-efficacy in course subjects for diverse students.

I. Students Learning Outcomes

Does the PNP approach support an inclusive learning environment? Does the PNP approach effectively deliver the targeted content to all students, regardless of their diverse backgrounds? To answer these particular questions, we collected data about this course across 16 sections in six academic years between 2018 and 2023. In total, 311 students have completed the course. Instructor A taught 155 students across eight sections, while instructor B taught 156 students in eight sections. The grade distributions of both instructors compared in Figure 5 are nearly identical, indicating the robustness of the PNP structure in mitigating biases across gender, rank, and ethnicity, for which Instructor A and B identify differently across in all three. For the remainder of our analysis of learning outcomes, data will be merged for both sections.

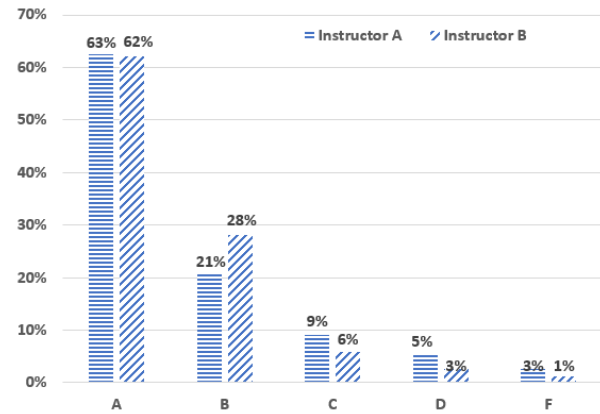


Figure 5: Grade Distribution Comparison Between Two Instructors

Among all students, 81% of the students taking the class majored in Engineering Technology or Computer Science, 10% are non-majors who took the class to fulfill their general education requirements, and 9% are classified as undeclared, meaning they have not yet declared their major at the time they took the class (primarily first-years and sophomores). Figure 6 illustrates the course grade distributions. It is observed that while non-major students may not perform as well as major students, over 72% of them still achieve a grade of B or higher in this class. As expected, undeclared majors, typically in their first two years, are the weakest performers in the class.

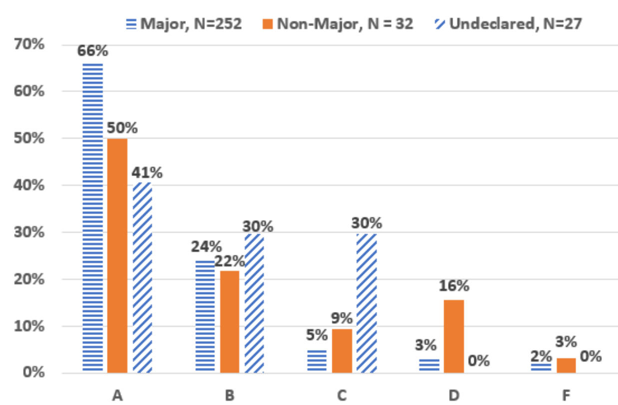


Figure 6: Grade Distribution for Major, Non-major, and Undeclared Students

Prior to Spring 2021, the course was only offered in a single section per semester, resulting in more than 90% of students being Juniors and Seniors. Most enrolled students were seniors fulfilling major requirements, with fewer opportunities for freshman and sophomores. With the introduction of the second section per term in Fall 2021, the composition of the class has shifted. Now, a significant portion of the seniors are non-major students, and about 40% to 50% of enrolled students are sophomores and freshmen. Because PNP required constant reflection, we were able to identify this changing student population and adjust our course materials to serve these younger students better in the later offerings of the course.

Table 2: Grade Distribution by Class Rank and Gender

	Classification				**Gender**		
Grade	First-year N = 4	Sophomore N = 53	Junior N = 157	Senior N = 97	Male N = 206	Female N = 95	Non-Binary N = 10
A	75%	51%	62%	69%	58%	69%	80%
B	0%	34%	24%	22%	29%	17%	0%
C	25%	9%	9%	3%	7%	7%	10%
D	0%	2%	4%	4%	4%	4%	0%
F	0%	4%	1%	2%	1%	2%	10%

Table 2 presents a comparison of grade distributions for different class ranks. Due to the low number of first-years (4), this data is presented, but is not considered any further. When examining the data for sophomores, juniors, and seniors, it is evident that seniors outperform juniors and sophomores, aligning with our expectations. Despite this, it is noteworthy that 85% of sophomores still achieved a grade of B or higher.

Compare to the national trends in engineering and engineering technology [19], this course has better gender diversity; out of 311 students, 66.5% of students self-identified as male, 30.4% as female, and 3.2% as non-binary. More than 80% of both male and female students have successfully completed the course with a grade of B or higher. The similar grade distributions between female and male students indicates that PNP promotes male/female gender equity and thus, an inclusive learning environment. Due to limited data on non-binary students, the same conclusion could be drawn for this population as well.

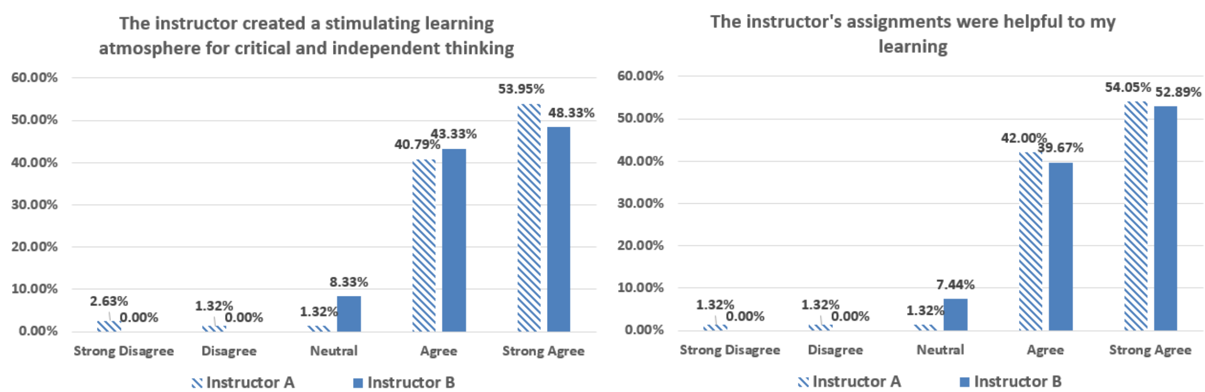
Overall, We are confident that the course provides all students with essential skills and foundations in electricity and electronics topics regardless of their gender, class rank, or prior academic background.

II. Students Learning Experience

To evaluate students' learning experiences using the PNP approach, students' responses in the course evaluation survey were examined. The survey is administered at the end of each semester, except during the COVID-19 period in 2020. Between 2018 and 2023, out of 110 students across Instructor A's eight classes, 78 samples were collected, resulting in a response rate of 69.1%; Instructor B collected 121 samples out of 157 students, yielding a response rate of 77.1%. We focused on four key metrics from the evaluations:

1. Did the instructor create a stimulating learning atmosphere conducive to critical and independent thinking?
2. Were the instructor's assignments helpful to my learning?
3. How much do you think you learned from this course?
4. How would you rate this course overall?

The first two questions were used to assess reflections on the learning experience after engaging in the PNP approach. The third question aimed at evaluating the self-efficacy of the students after completing the course. The final question provides insight on how students evaluated the course overall.



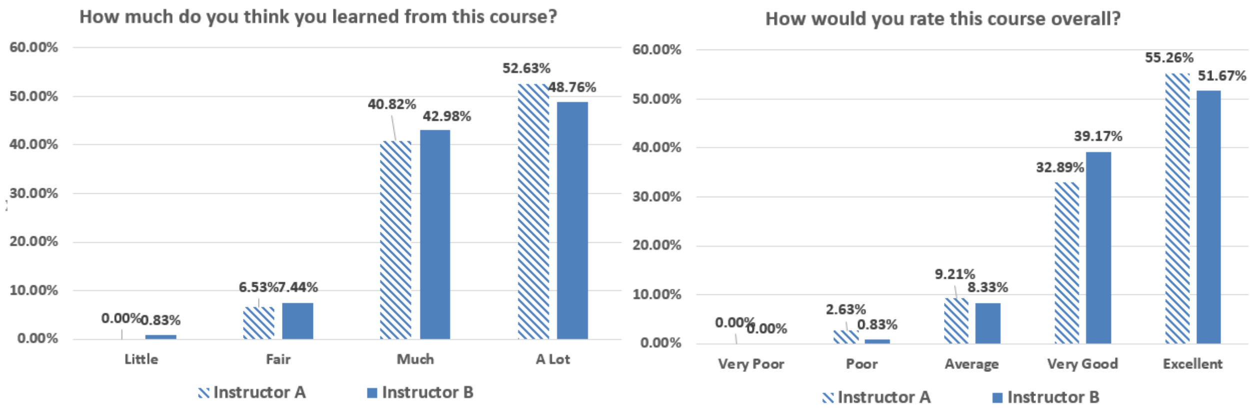
(a) (b)

Figure 7: Course Evaluation Survey Results I

Figure 7 aggregates the students' ratings for the first two questions across all sections for each instructor. Both instructors' course evaluations are almost identical, again highlighting the effectiveness of the PNP approach in mitigating bias. According to the data, more than 90% of students agreed or strongly agreed that the class created a stimulating learning atmosphere for critical and independent thinking, and more than 90% of students agreed or strongly agreed that the assignments were helpful to their learning. We attribute this success largely to PNP's supportive, engaged structure, reinforced by several comments from students:

"I worked on all assignments and most of them require you to pay attention and understand the concepts as you work."
"I learned an extensive amount! And the way the class was set up made it easier to work on assignments"
"I learned so much from this course coming in with zero knowledge of electricity. The assignments and teamwork were extremely beneficial to my understanding and they were set up in a way that helped me learn it in the best way possible. "
"I learned a lot from this course. I was very intimidated when we first started but I think the way the class is structured (consistent deadlines, teamwork, consistent quizzes) in a way that helped me a lot."

We believe the PNP approach also promotes students' self-efficacy, defined as one's own belief in their capability to reach the goals [20] [21], which correlates with motivation [22]. As an introductory course, it is important to boost students' motivation to be interested in learning in the future and building self-confidence, particularly in working with electronics. Akbari et al. [23] concluded that students' self-efficacy will positively impact their overall academic ability.



(a) (b)

Figure 8: Course Evaluation Survey Results II

The specific student course evaluation question "How much do you think you learned from this class?" best demonstrated the student's self-evaluation of learning, which we correlated with high levels of self-efficacy. Figure 8a shows that 93% of students reflected that they have learned "much" or "a lot" in the class. Many students expressed in survey comments how much they learned from the course, even though they entered with no prior experience. They reported feeling satisfied and confident by the end. For instance, Several students mentioned in the survey:

"I came into the class scared due to zero prior understanding and left feeling extremely confident."
"I learned a lot in this course. I have never been exposed to Arduino, breadboarding, and other things. This class made me comfortable with operating these things and building small projects from scratch..."
"I have learned a lot in this course. At the beginning I knew nothing about the materials, but now I am pretty confident in my skills. The work load was manageable and the perfect amount. I was actually able to understand the material which was something I thought was impossible in the beginning"

Finally, when asked "How would you rate this course overall?", the majority of students found their learning experience in this class enjoyable, also indicating a level of self-efficacy. 89% of all survey respondents rated the course overall as "Very Good" or "Excellent." as shown in 8b.

Conclusion

After evaluating six years and sixteen sections of the introductory electricity and electronics course, taught by two instructors leveraging the Plug -n- Play approach, we are confident that PNP is providing students with a highly engaging, effective learning environment which supports students from diverse backgrounds and experiences. The PNP approach also supports instructors by having a flexible structure, allowing them to try various active learning approaches in the classroom that can be tailored to fit instructors' teaching strengths and students' learning needs. Despite differences in the instructors' backgrounds, ethnicity, gender, years of experience, academic rank, degree fields, and teaching style, they received nearly identical positive outcomes in engagement level, grades, and course evaluation responses, demonstrating PNP's ability to mitigate biases.

Future work includes expanding the study to include more and different classes and more instructors, which will allow more reporting of granular data, including gender, class rank, and ethnicity. To enhance our understanding of student perspective more deeply, collecting qualitative data from focus groups and interviews are planned, which will enhance reporting on gender equity and inclusiveness observations. Finally, broader dissemination of the work is desired, including conducting workshops on how to implement PNP.

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Appendices

Appendix A: Observation Code Setup

Observation Procedure

The observer will observe for the entire class period (110 minutes). We chose to adopt from the BERI [16] observation procedure and observe the class in 5-minute intervals. During the interval, sets of students (in our case, a table of up to four students) were observed for one minute. Observers recorded their both the students' engagement code and course activity code for that minute, then proceeded to observe the next set. For example, if the instructor is giving a lecture and the student is reading the assignment document, the observer will mark "LE: M" in the observer ledger to indicate the activity was lecture and the student was engaged with the material. If the student transitioned to listening to the instructor, the observation would then become "LE: M, I" to record the transition to engaging with the instructor's lecture.

The observer needs to have a clear view of the student and their activity. The observer would move between three vantage points after each five minute interval to ensure a clear view of the student's activity. Due to the hands-on nature of the class, the observer's movements did not cause any interruption to students learning. Two class periods were used to train the observers and familiarize them with the codes and expected procedures. We compared their observation data in these two pre-study sessions to calibrate the observers on our expectation for each code. All observers were able to follow the procedure with minimal outlier data points.

Table 3: Students Engagement Code

Code	Description	Examples
D	Disengaged: any non-course related activities.	Leaving the room for any reason, surfing the internet, playing on cell phones.
M	Engaged with material alone	Reading instructions, typing into a worksheet, building a circuit alone.
P	Engaged with partner(s)	Discussing course material, reviewing a circuit together, pair programming.
C	Engaged with other students in class	Helping/seeking help from other teams, students becoming a temporary TA for a class.
I	Engaged with the instructor/TAs	Raising their hand, asking questions, listening to a lecture
F	Finished	Completed an activity early

Table 4: Course Activity Code

Code	Description	Examples
QA	Question & Answer (Q&A)	Facilitated discussion, Q&A on a reading
QZ	Evaluation	In-class evaluation, test/exam
TW	Teamwork	Hands-on activity, POGIL activity, circuit construction, pair programming
LE	Lecture	In-class demonstration, role-playing, storytelling
OT	Other Activity	Any divergence from typical class activity