Implementation techniques for Tinkercad's circuit simulator in introductory electrical and computer engineering courses

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1. Introduction and motivation

Over the past several decades, engineering programs have increasingly added introductory courses that do not rely on extensive prerequisites such as physics and calculus. These first-year experiences aim to make engineering more attractive, improve student motivation, and increase retention by providing early exposure to the discipline. In electrical and computer engineering (ECE) programs, such courses often cover exploration of the field, basic circuit analysis, problem solving, programming fundamentals, and integrated software-hardware projects. Usually, these courses utilize a lot of hands-on experimentation, which helps introduce abstract concepts in more relatable ways.

A persistent challenge in introductory engineering courses is addressing the diverse knowledge and experience levels among incoming students. While formal prerequisites can help, they can also create barriers to entry that disproportionately affect certain student populations. Students arrive with varying degrees of familiarity with electronics, programming, and technical problem-solving—some with extensive hobbyist experience or prior coursework, others with virtually none. This diversity presents a challenge: how to provide sufficient scaffolding for students with limited technical backgrounds while maintaining engagement for those with more experience.

The hands-on laboratory component of introductory courses can be augmented with simulation tools, which offer advantages such as accessibility, repeatability, and the ability to experiment without risk. The use of virtual tools in engineering education has been recognized as an effective method for fostering learning across diverse engineering disciplines [1,2]. Circuit simulation tools such as LTSpice [3] or Multisim [4] are widely used in ECE curricula but are typically introduced during second-year courses on circuit analysis. These tools can present significant challenges when introduced at the first-year level. For example, the conceptual difficulty of interpreting schematics can be intimidating for first-year students. As noted in [5], SPICE-like simulation tools "tend to provide a utilitarian user interface, with little emphasis on realistic depictions. This acts as a barrier to entry for novice users."

Tinkercad, which started as a 3-D design tool from Autodesk, now also includes a sandbox simulation of electrical and electronic circuits [6-8]. The software is web-based and features an intuitive graphical interface designed to be accessible even for pre-college students. Its simulation capabilities now extend to topics covered in typical undergraduate circuits courses. In addition, Tinkercad can be used to program Arduino and BBC Micro:bit microcontrollers, which opens opportunities for exploring integrated projects that combine software and hardware elements [9-11]. The platform's visual realism—components appear as they would on a physical breadboard—may help bridge the gap between abstract circuit concepts and physical implementation, particularly for novice learners.

While the potential benefits of simulation tools in introductory courses are well documented, less attention has been paid to how different implementation approaches affect student learning and laboratory preparedness. Circuit simulators like Tinkercad can be deployed in multiple ways: as an in-class demonstration and instructional tool, as a prelab activity where students replicate upcoming experiments, as a supplementary resource for independent practice, or as an integrated component of laboratory sessions. Each approach carries different implications for student engagement, time investment, and the development of both conceptual understanding and practical skills. Understanding which implementation strategies are most effective—and for which student populations—is essential for instructors seeking to maximize the pedagogical value of these tools.

This paper examines how different implementation approaches for Tinkercad affect student preparedness and learning outcomes in introductory ECE courses. We compare two sections of an introductory course: one with approximately 75 students in a 10-week term in the United States, and another with approximately 240 students in an 8-week intensive term in China. While there are structural and cultural differences between the two contexts, both courses share similar learning goals. The key difference lies in the implementation of Tinkercad: the US course uses it as an in-class instructional tool to support concept development, while the Chinese course assigns prelab activities where students replicate hands-on experiments in the simulation environment before attending lab sessions.

Prior work on this topic has established that students generally hold positive attitudes toward Tinkercad and that incoming students possess widely varying levels of technical preparation in circuit design, hardware, and programming [12,13]. Initial findings suggested that students felt more prepared for laboratory sessions after using Tinkercad, and many students voluntarily used the tool beyond required assignments. Faculty reported that implementation was manageable and observed benefits from the visual representation provided by simulation. However, these earlier studies did not systematically compare different implementation approaches or examine the relationship between implementation strategy and student outcomes.

The current study expands data collection through pre- and post-surveys, focus groups, and analysis of student work to address the following research questions: (1) What is the relationship between implementation approach and student laboratory success and completion rates? (2) What characteristics of Tinkercad do students perceive as most valuable, such as visual representation, accessibility, or the opportunity for risk-free experimentation? (3) What patterns exist in Tinkercad engagement relative to students' prior knowledge of course material? By examining parallel implementations across different pedagogical contexts, this work aims to provide insights for instructors considering how best to deploy circuit simulation tools to support diverse learners and reduce knowledge gaps among first-year engineering students.

2. Curricular and institutional context

Details of our curricular and institutional context were previously discussed in [12-14] and we are providing only a summary.

Portland State University (PSU) is an urban university with a diverse student population. The Electrical and Computer Engineering (ECE) department offers ABET-accredited BS degrees in both areas. The ECE department also has a long history of international collaborations, the most recent with Nanjing University of Post and Telecommunication (NJUPT) in China. Within this collaborative effort we have developed two new engineering programs that are based on the electrical and computer engineering programs at our university. This program is given the acronym PIN. Teaching in China is done in both English and Chinese. This and other collaborations provide opportunities to examine the effects of cultural and institutional differences and teaching practices on student learning.

2.1 ECE 101 Exploring Electrical Engineering

In this first-year ECE course students are introduced to this area of engineering with the intent of demonstrating all the different course and career areas that ECE engineers tackle. The main objectives are to acclimatize students to campus life, build a sense of community and belonging, while gently introducing the technical side of content and lab equipment through engaging activities, projects, and labs. More details on ECE 101 can be found in our prior publications [12-14].

Many topics in the class are introduced at the surface level, with the understanding that they will be explored more in-depth in the years to follow. The learning outcomes are accomplished through a series of in-class activities, formal laboratory sessions, and an out-of-class group project. The lab sessions focus most on gaining familiarity with common lab equipment and instrumentation, as well as basic circuit analysis. The project has a prompt that allows choice for creativity and uniqueness while providing constraints. In-class activities are aimed at providing students with a starting point to labs and the project. The in-class activities and lab prep are where Tinkercad was utilized in the course to help aid student learning and enable more experimentation, as discussed in section 3.1.

2.2. PIN 101 Introduction to Computer Hardware

This course is taught in China and was modeled after the course taught in the US. The biggest challenge in this course is the scale: our domestic courses have enrollments of around 40-70 students, while in China there are 240 students in two programs. Lectures and labs are done in person at both locations.

Labs form an essential part of the course, three related to electric circuits and two dealing with Arduino Uno. The first three support the introduction of concepts such as resistive circuits, Ohm's law, voltage and current dividers, and time-dependent R-C charging. The math and physics related to these concepts are relatively easy to develop intuitively and do not require extensive preparation. For Arduino Uno, we cover only the basics that require minimal experience with programming. However, we have found that this is enough to enable students to pursue fairly ambitious projects involving multiple sensors and actuators. The final course projects involving Arduino Uno have to be judiciously selected given the wide variety of student experience.

3. Why and what of Tinkercad

Tinkercad is a free, web browser-based app that covers 3D design, electronics, and coding [6]. It has special features that make it accessible for K-12 use and was initially aimed at middle school and high school students. As the Tinkercad modeling program continued to grow, many new features were added. In particular, Autodesk added interfaces to its more professional-level software, such as Fusion or Eagle, which helps students get a taste of what their future workplace may look like.

Tinkercad supports Arduino Uno and Micro:bit microcontrollers. Programming is done either through a graphical interface called CodeBlocks or through a text-based interface. Microcontrollers can be interfaced with electronic circuitry so that code development can be done in parallel with hardware development.

Extensive literature on projects using Tinkercad exists both in print as well as video tutorials. Based on our experience, it has been helpful in reducing the barrier to early engagement in authentic engineering projects through:

A. Easy access
B. Intuitive graphical interface that closely mimics real-life hardware
C. Simultaneous development of hardware and software projects
D. Combining simulation with building circuits in the lab and testing them in real life

Next, we discuss how Tinkercad is currently used in our ECE and PIN courses. In ECE 101, Tinkercad is used primarily for in-class interaction, prelabs, and instruction, but in PIN 101 it is primarily used for formal pre-lab assignments.

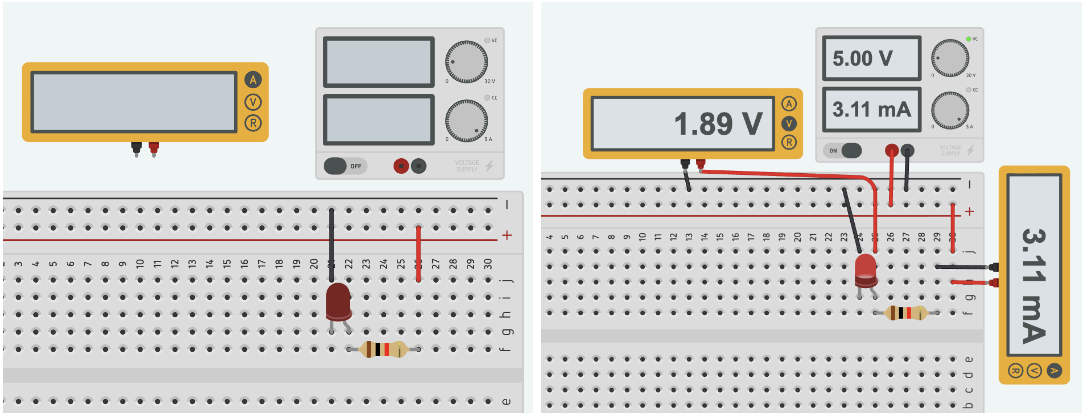
3.1 Implementation in ECE 101

The ECE 101 course is a level-one introductory course with light math prerequisites such as algebra and trigonometry. It is typically taken by Freshman in their first quarter at PSU. Therefore, the course has the challenge, as discussed above, of a wide range of student backgrounds in math, science, writing, reading, etc. Therefore, this course needs to instill common practices and knowledge that will be needed in the years to come, as well as an engineering mindset to apply problem solving skills. To accomplish this background leveling, topics for the course include career paths within electrical and computer engineering, research and writing as a scientist, “engineering math,” circuit analysis, digital electronics, and engineering ethics, in respective order.

The introduction to circuit analysis and digital electronics portion of this course is the area that utilized Tinkercad. The students have a separate weekly laboratory section. The electronics-related topics of the lectures and labs combined are as follows:

- Ohm’s law
- Series and parallel circuits
- Capacitive and inductive circuits
- Transistors
- Logic gates and integrated circuits chips
- Arduino
- Variable power supplies

Tinkercad was first introduced during lecture to have the students set up an account and join the class online where activities could be assigned for completion. The first activity was just introducing the basic components of a circuit: a power supply, a bread board, wiring, a load, and resistor, as well as a multimeter. This setup can be seen in Figure 1. Students were given the activity with components not placed together, Figure 1a, and a schematic to follow to build the simple circuit in Figure 1b. For many of the students this is their first experience with even the simplest circuitry. Many students had difficulty navigating the interconnections of the breadboard, as well as the anode and cathode of the LED. This in-class activity was done in the same session as discussions on “what is electricity and electronics?” which included the topics of resistance, resistor values, and electrical engineering tools (such as the multimeter). The students gain insight into common lab equipment implementation, and are shown the difference between parallel and series given the difference between a voltmeter and ammeter for measurement.

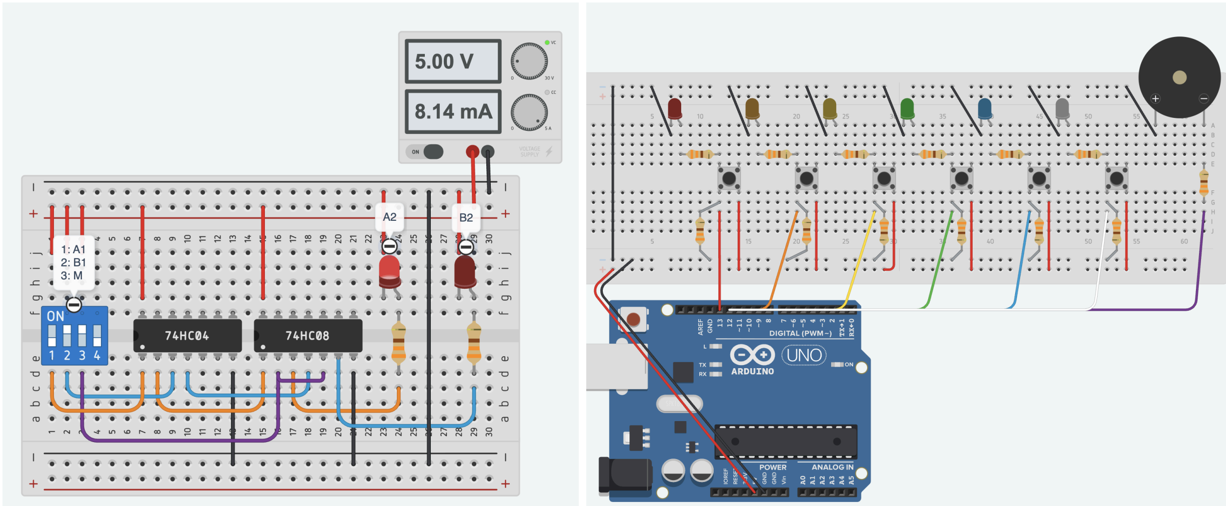


(a) (b)

Figure 1. Activity of a basic circuit breadboarding for a common lab equipment:(power supply, wires, and multimeters with a load (LED) and resistor in Tinkercad: a) setup given to students to tinker, b) final basic circuit simulation.

As the course progressed through the topics discussed above, the lectures would include a Tinkercad activity to complete together with discussion. This included activities with multi-load circuits in series and parallel, implementing switches and potentiometers, demonstrating the polarized capacitor, introducing transistors as electric switches, and creating logic gates, as well as implementing integrated circuit chips (ICs) to develop a digital logic system. Students are asked to develop a digital system from scratch first defining their input and output variables, as well as summary statements, how the system operates. They then turn this into a circuit diagram from a truth table and simplified boolean expressions. Finally, the students are asked to implement the system using Tinkercad to demonstrate the functioning system. A student example of a digital logic system can be seen in Figure 2a where the inputs are shown as a labeled DIP switch and the output of the system as labeled LEDs to demonstrate ON or OFF.

In addition to the required in-class activities, Tinkercad was used within the labs both as optional prep work beforehand and as a full lab to introduce Arduino hardware and programming. This year, unlike the 2024 course, students were given a more open-ended introduction to Arduino with extended “challenges” to progress their understanding of implementation. For Lab 4, students were tasked to build a memory game in Tinkercad that interfaced with the Arduino to have the user push the buttons associated with the random pattern of LED flashes. Students were then challenged to add more components including a buzzer to go off when the user failed to recreate the pattern. Students were provided a circuit schematic and base code to start. In Figure 2b, a completed Lab 4 is seen. This was the only introduction to Arduino in the class and never discussed during class time. However, many student groups used Tinkercad and Arduino as a way to prototype for their final projects.



(a) (b)

Figure 2. a) Digital logic system using logic gate ICs, a DIP switch, and two LEDs as outputs. b) Lab 4: Arduino memory game.

3.2 Implementation in PIN 101

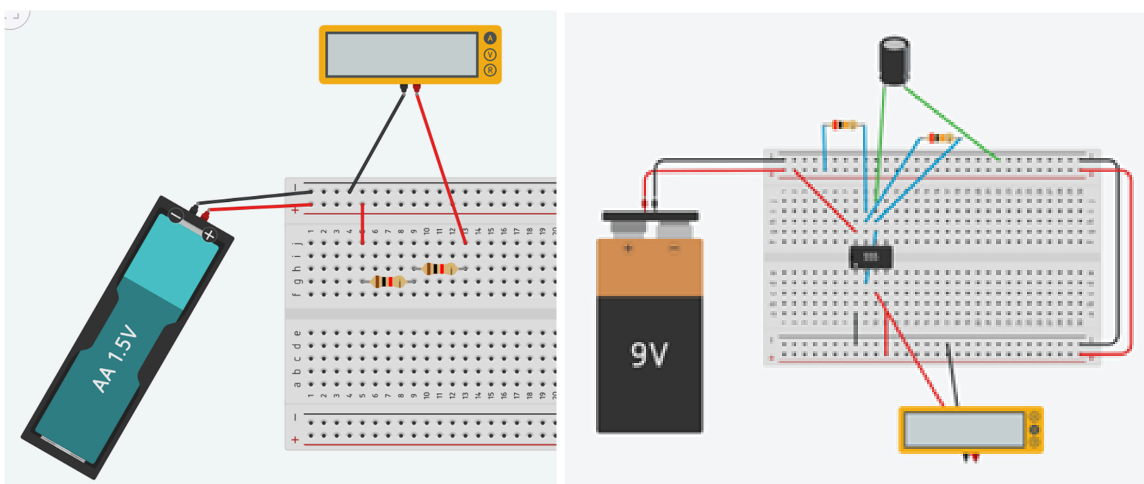
PIN 101 is the first engineering course in our collaborative program in China. Like ECE 101, it has no formal math or physics prerequisites, though students take calculus and linear algebra concurrently. The course emphasizes exploration, teamwork, and projects. It covers basic resistive circuits, voltage and current dividers, and R-C charging before progressing to applications such as NE555 timer circuits. Two additional labs introduce Arduino programming fundamentals. A detailed description of the course structure, lab sequence, and learning objectives is provided in [12,13].

Tinkercad is used primarily for prelab assignments. This was motivated by two observations: first, many students arrived at laboratory sessions without completing the required preparatory reading or video materials; second, it became clear that laboratory experiments could be closely replicated in the Tinkercad environment. This prompted us to structure prelab exercises that would ensure meaningful accountability and preparation.

Each prelab assignment requires students to build and simulate circuits in Tinkercad that mimic a portion of the upcoming laboratory experiment. For instance, before the R-C charging lab, students construct the same circuit they will later build on a physical breadboard. They work with realistic graphical representations of breadboards, wires, and components rather than abstract schematics. This approach reduces cognitive load for novices who have not yet developed fluency in reading circuit diagrams. It also enables exploration of “what if” questions

- such as changing component values and observing the effects - that would be impractical during time-limited lab sessions.

Figure 3 illustrates two simulations in Tinkercad: part a) is from the first lab showing students how to set up current measurements in a simple resistor circuit. Part b) is a more complex circuit where the NE555 is used as an astable oscillator. In part b) students can adjust timing components and directly observe changes in oscillation frequency before they build the physical circuit. Despite thorough preparation through simulation, the physical implementation remains demanding because it requires careful attention to wiring details and debugging skills that simulation alone cannot fully develop. This progression from simulation to building hardware thus serves complementary learning objectives: the prelab builds conceptual understanding and procedural familiarity, whereas the hands-on lab develops practical construction and troubleshooting abilities.



(a) (b)

Figure 3. Tinkercad simulation of a) current measurement in resistor circuit, b) NE555 astable circuit.

4. Assessment

Previous phases of this research collected preliminary data on student technical preparedness (hardware and software readiness), student attitudes toward Tinkercad, instructor experiences with implementation, and differences between institutions. Initial findings suggest that students felt more prepared for laboratory sessions, held generally positive attitudes toward Tinkercad, and voluntarily used the tool beyond required assignments. Faculty reported that implementation was manageable and observed benefits from the visual representation provided by simulation.

The current phase of research expands data collection through pre- and post-surveys, focus groups and analysis of student work to examine: 1) relationships between implementation approach and student laboratory success and completion rates, 2) student perceptions of

Tinkercad's most valuable characteristics (such as visual representation, accessibility, or risk-free experimentation), and 3) patterns in Tinkercad engagement relative to students' prior knowledge of course material.

4.1 Students' prior experience

Students in both of our programs show a great diversity of experiences and self-efficacy. We have focused on some aspects that are specific to the course and others that are more general. A full survey listing with potential answers is given in the Appendix. Survey results are presented in Figures 4 to 7 for the Fall 2025 section of ECE 101, and for Fall 2024 and Fall 2025 sections of PIN 101. For ECE 101 Fall 2025 return rates were 27 out of 72 (37.5%), for PIN 101 Fall 2024 they were 128 out of 240 (53%), and for PIN 101 Fall 2025 140 out of 240 (58%). The survey questions included:

- Q10: How much experience do you have working with electrical circuits, either as real hardware or in simulation? See Figure 4.
- Q11 - In your high-school, how often did you use electrical engineering instrumentation, such as digital multimeter, oscilloscope, signal generator, or similar? See Figure 5.
- Q12 - How would you rank your programming skills (in any programming language)? See Figure 6.
- Q18 - How confident are you that you can apply your current math skills to solving engineering problems? Note that in this course we only expect high school level math preparation. See Figure 7.

From these results we can conclude:
Q10: The average student has learned somewhere in between a "little bit" and "moderate amount" about electrical circuits. Therefore, we have to assume very little if any prior knowledge in this area.

Q11: Answers to this question confirm the results from Q10: more than half of the students have used electrical lab instruments "rarely" or do not know what they are. The majority of students are complete novices and will require additional training in this area.

Q12: Compared to their hardware-related experience, PIN students are a bit more positive about their programming skills and experience, but roughly ⅓ of them rank their programming skills as "poor" or "terrible." That is a significant portion of the population that has to be treated as complete novices. ECE students rank their programming skills even lower than PIN students.

Q18: In general, students are positive about their ability to use math to solve engineering problems with roughly 60% in both years being “somewhat” to “very confident”. ECE students are even more confident than their PIN peers.

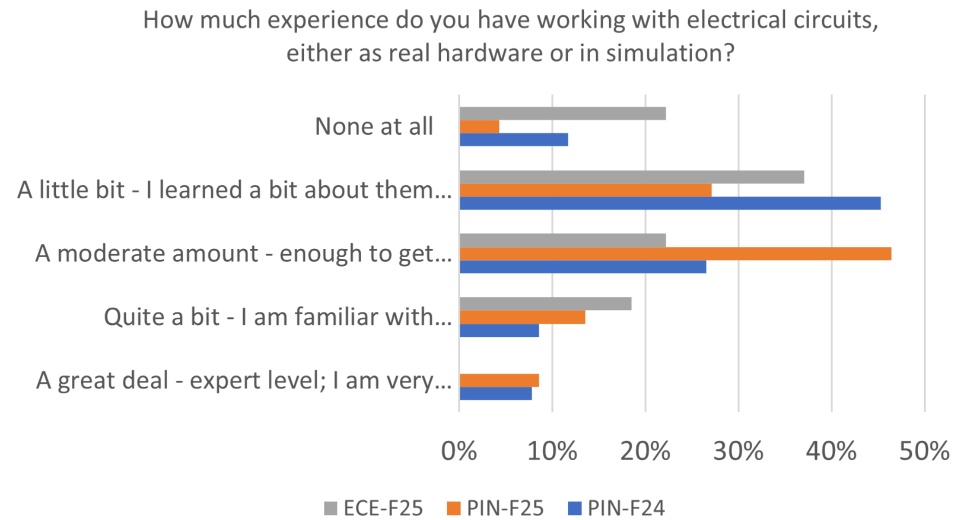


Figure 4. ECE and PIN 101 survey results from Fall 2024 and 2025. Q10: Student self-evaluation of prior experience with electrical circuits.

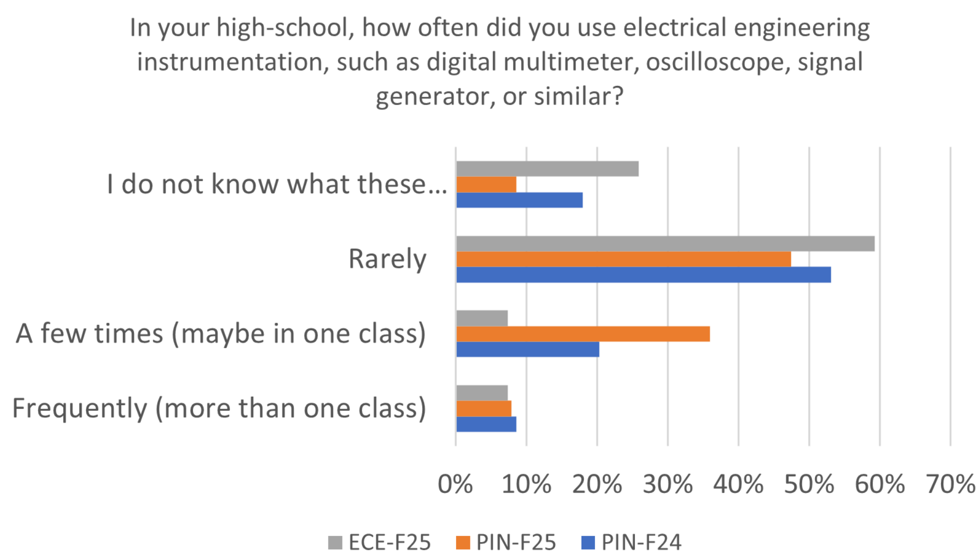


Figure 5. ECE and PIN 101 survey results from Fall 2024 and 2025. Q11: Student self-evaluation of prior experience with specific electrical engineering instrumentation (lab equipment).

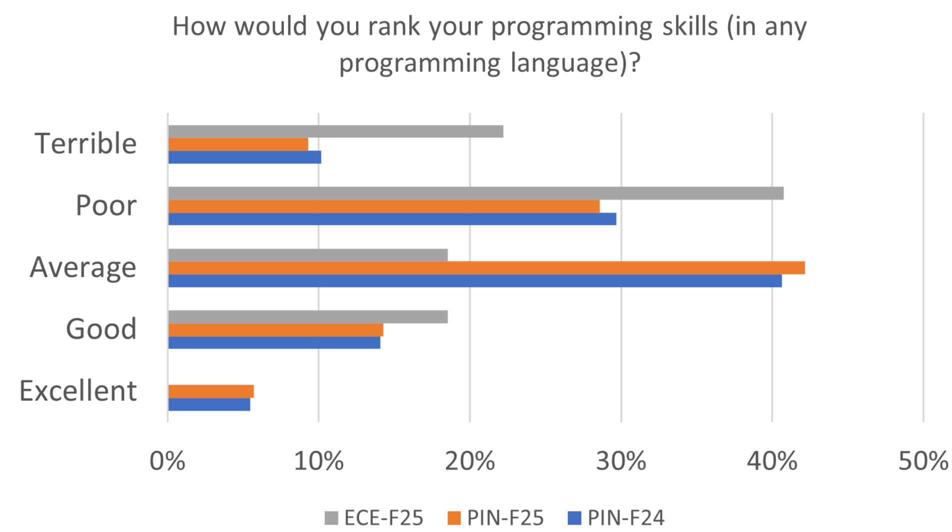


Figure 6. ECE and PIN 101 survey results from Fall 2024 and 2025. Q12: Student self-efficacy with respect to programming skills (any language).

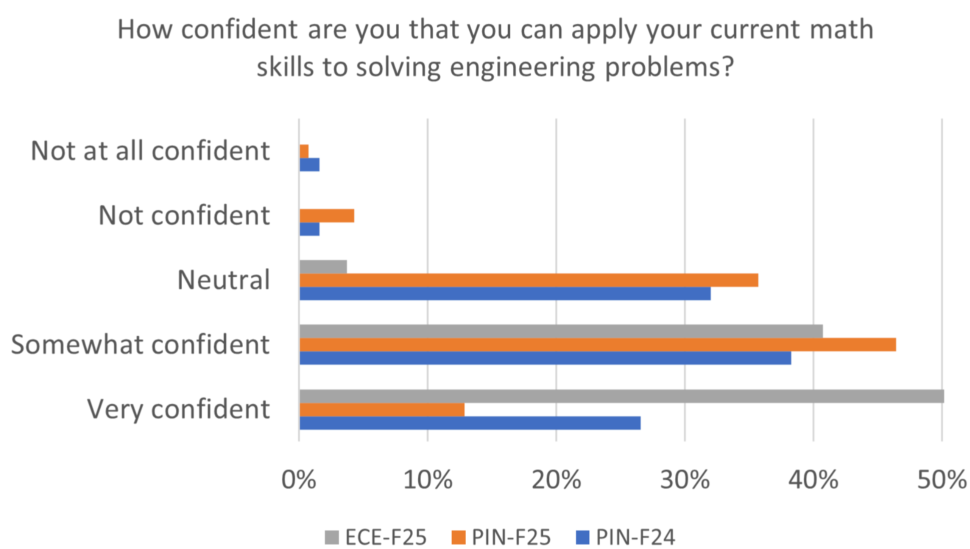


Figure 7. PIN 101 survey results from Fall 2024 and 2025. Q18: Student self-efficacy with respect to math skills.

Overall, these results give us reasonably good insight into students' preparation and their self-efficacy in a few areas important for this introductory electrical engineering course. They verify our experience that students have widely varying degrees of experience and confidence in their abilities and we must take this into consideration when designing course activities, especially the lab exercises and projects. One way to equalize the differences is by using tools that would enable easy experimentation for those without much experience but also have enough advanced capabilities so that more experienced students can still find it useful to learn.

4.2 Tinkercad post-course surveys

In both ECE and PIN courses we regularly run post-course surveys to assess students' perceptions of Tinkercad's usefulness. For easier analysis we plot questions in two groups: a) related to Tinkercad's general usefulness (see Figures 8 and 10), and b) specific uses in classes (see Figures 9 and 11).

ECE 101 survey results

Figure 8 demonstrates students' perspective on Tinkercad being motivating, useful, and easy to use. It is important to point out the difference from the 2024 and 2025 cohort. A change to highlight from the 2024 to 2025 course was the formalization of in-class Tinkercad activities. The 2024 lecture simply used the activities as part of the lecture, but students weren't required to submit their results as they were in 2025.

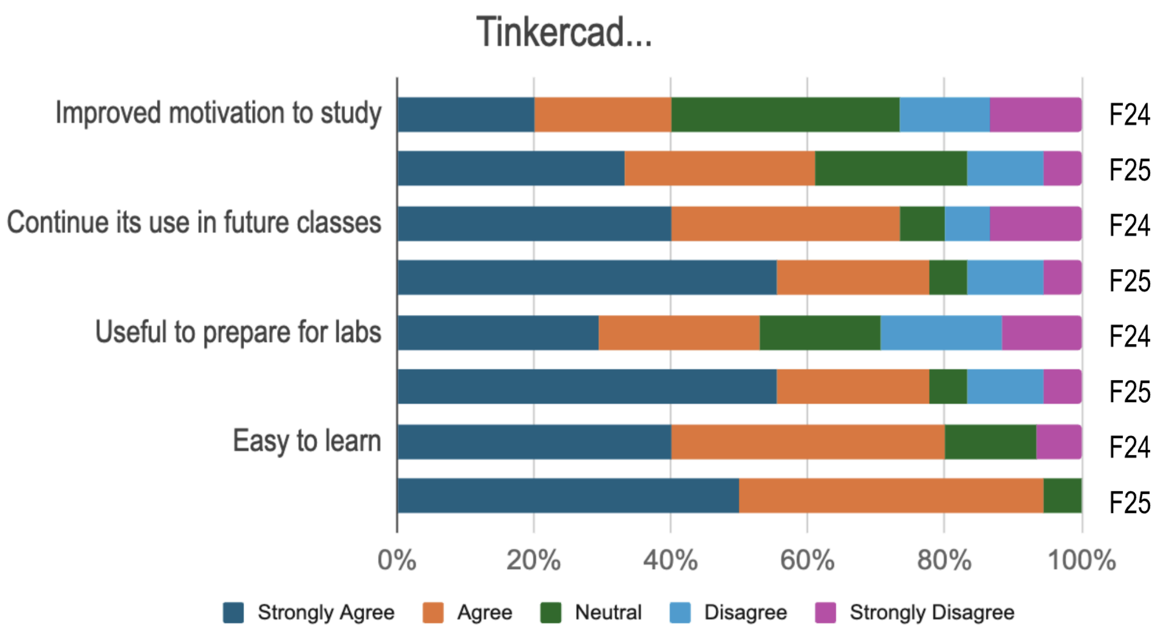


Figure 8. Student survey results regarding use of Tinkercad. ECE 101, Fall 2024 (F24) and 2025 (F25).

For Figure 9, we are interested in how Tinkercad affected students' understanding of Arduino hardware and programming, and understanding of circuits. There is little to no change in the responses. However, the Arduino assignment from 2024 was changed in 2025 to go more in depth with sensors, outputs, and coding. This movement forward can be seen in the students' final group project where 85% of students used the Arduino with sensors and outputs (motors, LEDs, etc.). The larger positive change in "understanding circuits" from Figure 8, could also come from required in-class assignments where students are taking the material more seriously.

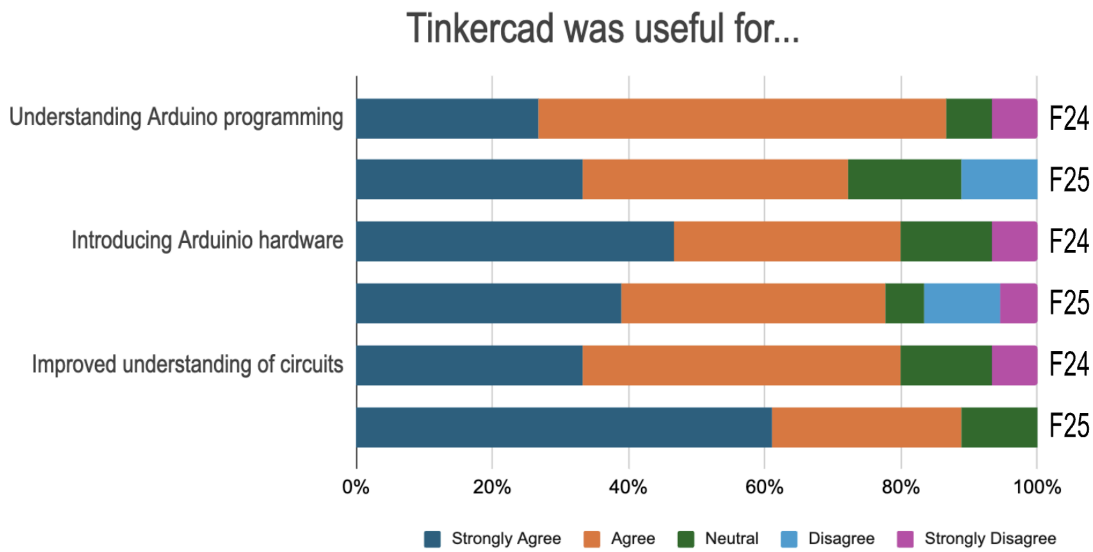


Figure 9. Student survey results regarding Arduino hardware, programming, and electric circuits for ECE 101, Fall 2024 and 2025.

PIN 101 survey results

From Figures 10 and 11, we can observe a decrease in the students Strongly Agreeing with various statements from 2024 to 2025. At the same time the number of students Agreeing with them increases so that the total of Strongly Agreeing and Agreeing is still around 80%. We consider this to still be a positive result although we may need to explore more carefully the reasons for the seeming reduction of enthusiasm. Return rates for Fall 2024 were 114 out of 240 (47.5%) and 132 out of 240 (55%) for Fall 2025.

One notable exception to this observation is the last question in Figure 10: “Tinkercad was easy to learn.” Here we observe that the total of Strongly Agree and Agree fell from over 80% to just over 60%. We speculate that this is due to transition to a new instructor and organization of the labs. In the 2025 section, Arduino labs and instruction were shifted to the end of the class which may have caused logistical problems. To address this, we will need to examine how Tinkercad is being introduced and ensure there is adequate follow up throughout the class.

It is also worth pointing out that over 80% of PIN students Agree or Strongly Agree that Tinkercad was “Useful to prepare for labs” (see Figure 10). On the other hand, 60% of ECE students Agree or Strongly Agree (see Figure 8). This is a direct reflection of the different emphases: in PIN we have required pre-lab assignments whereas they are less formal and optional in ECE.

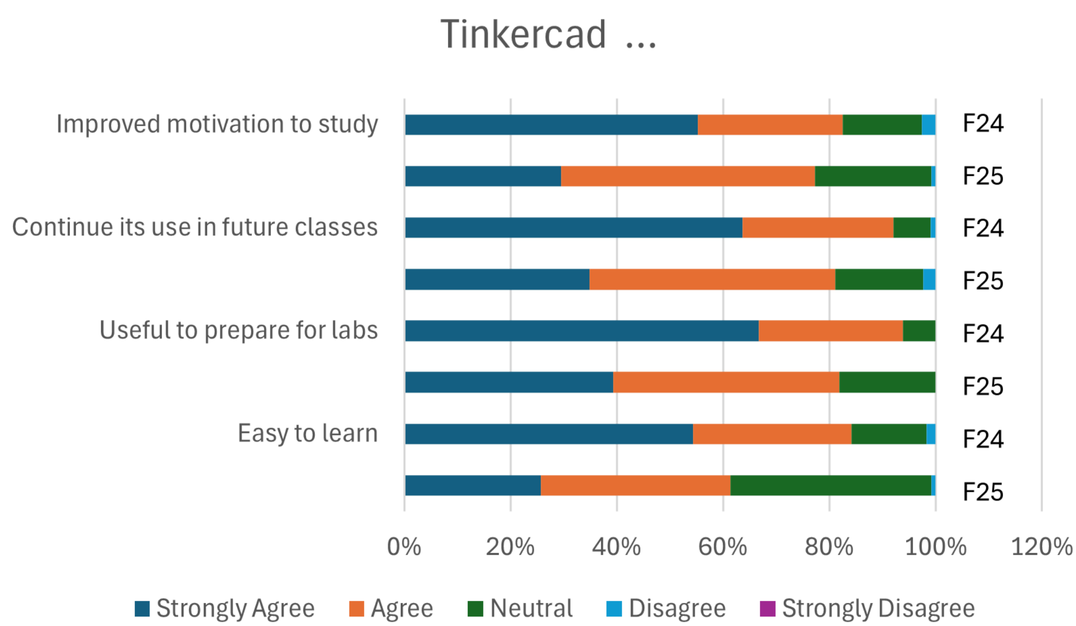


Figure 10. Results of student survey in PIN 101 for Fall 2024 (F24) and Fall 2025 (F25). Questions related to the general effects of Tinkercad on student learning and motivation.

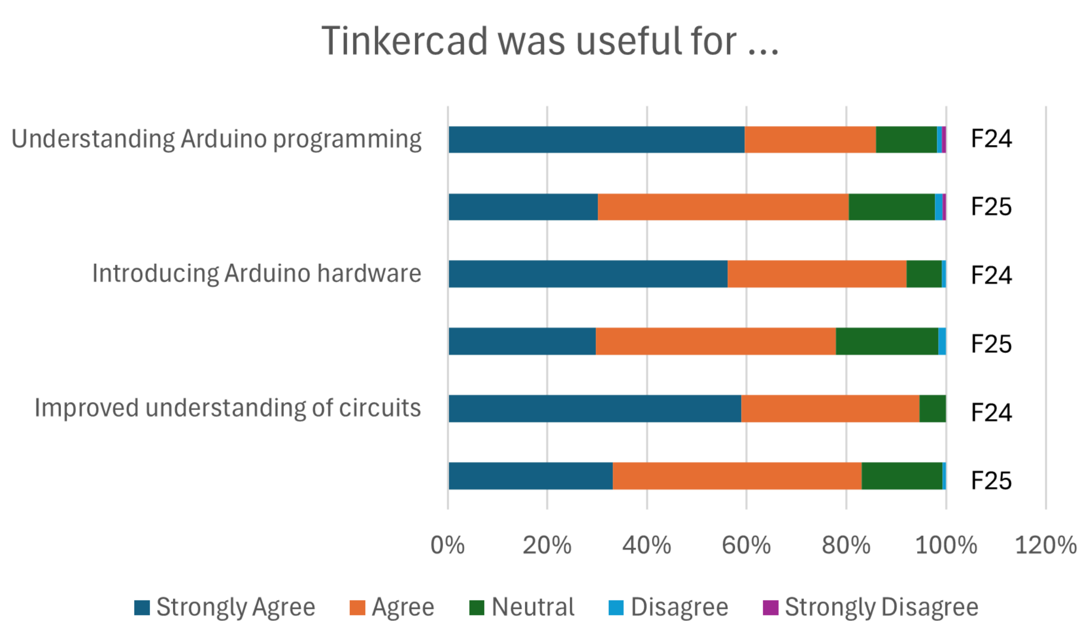


Figure 11. Results of student survey in PIN 101 for Fall 2024 (F24) and Fall 2025 (F25). Questions are related to the specifics of the course: Arduino hardware, programming, and electric circuits.

In comparison to one another, PIN and ECE both have a diverse group of student backgrounds. They both show positive outcomes with the use of Tinkercad in post surveys. It is important to note that the instructor for ECE was consistent from Fall 2024 to Fall 2025 term, while there was a new instructor for PIN in Fall 2025. This is important because it provides insight into the growth of student learning when either a consistent instructor is in place or an instructor who knows the software and assignments well from previous experience.

4.3 Other assessments

In addition to surveys, in PIN 101 we examined prelab assignment completion rates as a measure of student engagement with Tinkercad. These assignments are scored on submission rather than correctness and contribute minimally to the overall lab grade, so high completion rates suggest voluntary engagement rather than grade-driven compliance. As shown in Figure 12, completion rates for circuit-focused prelabs (Ohm's law, R-C charging, and NE555) consistently exceeded 70% across both cohorts, with most labs approaching or exceeding 80%. The notably lower completion rate for Arduino prelabs in Fall 2025 (~52%) coincided with a schedule change that placed these assignments during the project phase when students were focused on their final projects, which themselves rely heavily on Arduino. The sustained relatively high completion for circuit-based prelabs, despite minimal grade incentives, suggests that students perceived value in using Tinkercad to prepare for laboratory sessions. This confirms findings from student surveys and the focus group.

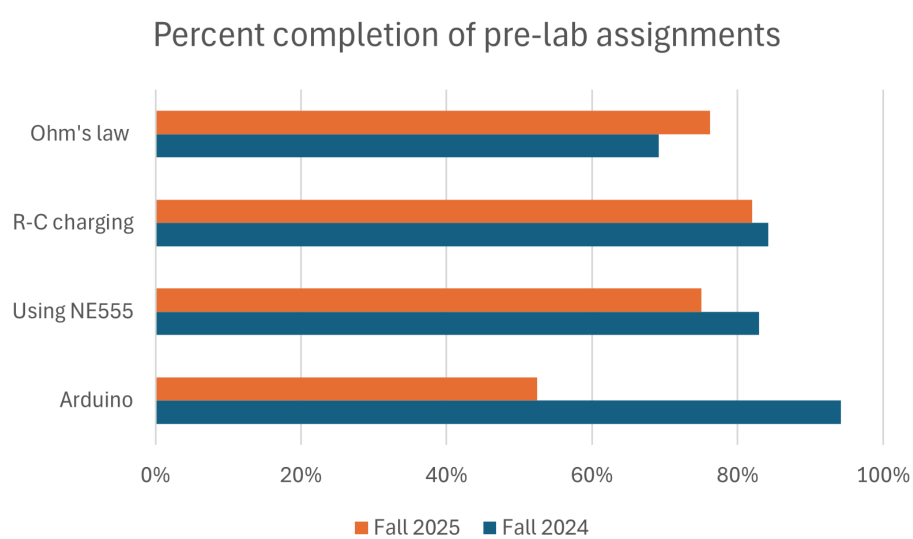


Figure 12. Percent completion rate of PIN 101 pre-lab assignments consisting of simulations in Tinkercad. The total number of students was 240 in the Fall 2024 and 244 in the Fall 2025.

For the long-term creative team project in ECE 101, there was a continued uptick for the use of Tinkercad. The course or guidelines of the project do not require the students to use any particular type of electrical components. The students could simply use two switches and an LED for the project to meet the requirements of "3 electrical components." However, 54% reported using Tinkercad to design and implement their project. This value is slightly up from 50% for the previous Fall 2024 term. More importantly, the depth that students went this year in Tinkercad and using microcontrollers was outstanding. The students' designs were more complex in the 2025 term with 62% using at least one microcontroller, 54% using logic integrated circuit chips, and 85% using one or more sensors (motion, force, tilt, etc.).

4.4 Focus group results

In November, 2025, we held a focus group of 8 first-year Chinese students to learn more about their experiences using Tinkercad. The students who participated in the focus group were class monitors for each of the 8 sections of PIN 101. Class monitors are student representatives who often serve as liaisons between instructors and students. These students were selected for the focus group because of their potential to not only speak for themselves, but also represent the experiences and interests of their classmates.Their responses in this focus group shine some light on the results of the survey and provide some additional information.

In the focus group, most students responded positively to questions about their experiences with Tinkercad. They rated the ease of learning Tinkercad between 5-8 on a 10 point scale, with 10 being the easiest, despite the fact that none had previous experience with simulation software and most had learned Tinkercad on their own by watching videos, reading professor documentation, and trial and error. Those who rated the ease of learning Tinkercad between 5-6 emphasized that they had difficulty learning to build circuits, not learning how to use the software.

Focus group students commented on several features of Tinkercad that they preferred to physical experiments. They described Tinkercad as safer, with more reliable components, and easy to manipulate circuit configurations. Several students elaborated on how the ease of manipulating components helped them understand how circuits work. One student said, "You can show the code here is a circuit, and here is code. You can choose stripe, switch box or C, and you can edit both of them." Another commented, "it's very helpful to help me [find], oh, this restricts resistance can cause more problems." The ability to map out circuits before the lab helped students save time during the lab because they already understood how the components were supposed to fit together, eliminating the need for physical trial and error. Although few of them used Tinkercad for their final projects, several acknowledged its usefulness for checking the accuracy of their circuits. One student said, "If there is something wrong with the circuit, I will go back to Tinkercad." Students also had positive experiences with Arduino programming in

Tinkercad. They found that programming in Tinkercad saved time because they were able to test and change code before applying it to the physical components.

This focus group shines some light on the survey results, and supports Tinkercad's utility in understanding circuit design and Arduino programming in a safe environment where it is easy to experiment, change configurations, and learn about how components fit together. Students can do this without worrying whether poor results were due to faulty components or a mistake in their design. This can improve motivation, as one student explained, "...if we always do lamps on the physical breadboard, and it's often failed, it may give students bad feedback. [But] if we know some basic information, basic knowledge, we may [succeed]. And it's a positive feedback and makes students to learn, love to do the lab."

5. Conclusions

The data presented in this paper confirms the positive effect the Autodesk software Tinkercad has on introductory learning in the field of electrical and computer engineering. Having three years of data to demonstrate the benefits from the student perspective certainly solidifies this conclusion [12,13]. What is extended in this paper is the pre-initial analysis, the difference from year to year, and more insight as to why Tinkercad has such a positive impact through a qualitative focus group.

From the initial survey data, we can confirm that both groups, PIN and ECE, hold diverse backgrounds in electrical circuits and instrumentation before arriving as freshmen in the program. The majority of students for ECE Fall 2025 had little to no experience with electrical circuits and instrumentation, but 40% of students did have experience coming into the introductory course. While on average only 18.25% of students completed the optional Tinkercad prelabs in ECE 101, this could have demonstrated that this percentage of students which opted into the extra work were the ones that needed the simulation to have a stronger outcome in the labs. As the percentage of completion decreased with each prelab 21%, 21%, 13%, and 18%, Lab 1, 2, 3, 5 respectively, students may have gained confidence in the common lab equipment and implementation. Future studies could look into this correlation further through surveying.

Another key takeaway in the initial survey data is the difference from year to year with experience. If we observe the PIN data from 2024 to 2025, we can see shifts in experience with students entering the same program. Again, allowing us to see that the curriculum really needs to be applicable and engaging to all levels. We can also see the difference between PIN and ECE in self assessment of programming skills. The ECE course is significantly in the "poor" and "terrible" range but PIN has more of an "average " to "poor" majority. However, when shifting to confidence of abilities using skills, the ECE students felt more confident than PIN students.

This demonstrates that the culture also comes into play in students' background and therefore readiness. Further understanding of this could provide insight as to how this could affect student learning.

In the student Tinkercad satisfaction survey, an upward trend is seen from year to year for ECE of 20% or more. This is important in comparison to PIN as their data demonstrates a downward trend for this year in comparison to the previous year. As discussed above, this could be due to a number of factors including instructor consistency or software experience. However, it is important to recognize that overall the student perspective on Tinkercad in furthering their learning is very positive for both years, never dropping lower than 60% in agreement that Tinkercad was an additive to student learning. The majority of the outcome values were closer to 80 and 90%. It would be an important next step to assess what could affect the outcome of student perception of Tinkercad in terms of how it is presented, guided mentorship, required assignments, timing of survey, etc.

The focus group provided insight into a more qualitative student perspective, answering the question of "what is it about Tinkercad that makes it such a great tool for introductory electrical and computer engineering courses?" The biggest highlights are allowing students to feel safe, work with reliable components, save time, and the ease of reworking and testing designs. The focus group also confirmed the quantitative data which displayed the ease of learning and using Tinkercad as one of the contributing factors to its impact. The focus group students also mentioned using Tinkercad even after building the physical model as a debugging tool, suggesting that it is visually easier to map, isolate, and test circuit components.

The use of microcontrollers past the single laboratory assignment demonstrates the ease of implementation with Tinkercad. The focus group supported this by providing context that the Tinkercad environment allowed students to experiment and learn Arduino in a safe way without worrying about poor results. This is seen in the complex designs of the ECE final projects as well where 85% of groups used sensors that they did not have background knowledge on and were not in the curriculum of the course. The Tinkercad software allowed students to extensively test their designs, implement them with an array of components, and debug their physical models successfully.

Overall, this paper serves as a continued attempt to demonstrate the positive impact the sandbox simulation environment of Tinkercad has on student learning in electrical and computer engineering introductory courses. It highlights the continued positive trend of student perspective in using Tinkercad. It confirms the diverse background of the students in each class, as well as year to year. It provides us insight into the specific reasons why Tinkercad is a competent and useful tool for students. And it opens up more areas of interest for future studies including year to year consistency of instructors, instructor Tinkercad experience, and assignment implementation and structure. This research allows us to see the benefits of sandbox simulators alongside the physical components of electrical and computer engineering curriculum.

In the future, we plan to examine how early exposure to Tinkercad supports continuity in students' learning experiences as they progress through the curriculum. Evidence that Tinkercad streamlines the transition between courses is already qualitatively apparent through its copious use by students in ECE 171, an introductory course on digital logic taken one term after ECE 101. Because students in ECE 171 are required to construct circuits on physical breadboards, Tinkercad was not originally a required instructional tool in the course. Nevertheless, we observed that students who were introduced to Tinkercad in ECE 101 naturally gravitated toward the platform to prototype and simulate digital designs prior to constructing them on physical breadboards. Furthermore, as discussed above, we found that Tinkercad aided students in debugging designs, thereby reducing the overall time required to complete assignments. In response to this widespread and voluntary adoption, we have since modified the ECE 171 syllabus to formally incorporate Tinkercad as an instructional resource. While these observations are thus far anecdotal, we hope to quantitatively investigate the impact of Tinkercad on student preparedness, confidence, and conceptual understanding more broadly across the ECE curriculum.

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Appendix A. Survey regarding prior experience

This set of questions is meant to give us some idea about your background and preparation for this course. Your answers will help us plan our activities better. There are no right or wrong answers in this survey, so answer the best you can. Do not spend a lot of time trying to figure something out - a good guess is what we are looking for.
…

I would like to find out if you have heard anything about electrical and computer engineering topics. It is OK if you did not have any experience with any of these topics.

Q10: How much experience do you have working with electrical circuits prior to this course, either as real hardware or in simulation?
- A great deal - expert level; I am very familiar with electrical circuits
- Quite a bit - I am familiar with electrical circuits but not an expert.
- A moderate amount - enough to get me started without much trouble.
- A little bit - I learned a bit about them but have forgotten most of it; I would be largely starting from zero.
- None at all

Q11: In your high school, how often did you use electrical engineering instrumentation, such as digital multimeter, oscilloscope, signal generator, or similar?
- Frequently (more than one class)
- A few times (maybe in one class)
- Rarely
- I do not know what these instruments are

Q12: How would you rank your programming skills (in any programming language)?
- Excellent
- Good
- Average
- Poor
- Terrible

Q13: Which programming language are you most familiar with? You can enter more than one choice. If you have not done any programming before coming to the Institute then select "None".
- C
- C++
- Matlab
- Python
- Java
- Other
- None

Q14: During your last two years in high school, how many team (or group) projects did you work on as part of class activities? They did not have to be in technical areas.
- None
- A couple
- 3 - 5
- more than 5

Q15: If you did a team or group project, what was the topic? Pick one that you remember the best. One sentence description is OK.

In this section I would like to get a sense of what your expectations and confidence are.

Q17: How confident are you that you will be able to complete a team project that involves electrical circuits and/or some programming?

- Very confident
- Somewhat confident
- Neutral
- Not confident
- Not at all confident

Q18: How confident are you that you can apply your current math skills to solving engineering problems? Note that in this course we only expect high school level of math preparation.

- Very confident
- Somewhat confident
- Neutral
- Not confident
- Not at all confident

Q19: What do you think this course will be about? What do you think you will learn? A couple of sentences would be enough but feel free to write more.

Appendix B. Survey regarding Tinkercad use

Q1

We would like to find out more about your experience with TinkerCAD. We will use the results to improve the labs and courses so your input is very valuable.

	Strongly Agree	Agree	Neutral	Disagree	Strongly disagree
Tinkercad was easy to learn	○	○	○	○	○
Tinkercad improved my understanding of circuits	○	○	○	○	○
Tinkercad was useful to prepare for labs	○	○	○	○	○
Tinkercad was useful for introducing Arduino hardware	○	○	○	○	○
Tinkercad was useful for understanding Arduino programming	○	○	○	○	○
I would like to continue using Tinkercad in future classes	○	○	○	○	○
Tinkercad improved my motivation to study	○	○	○	○	○