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Applying Problem-solving Before Instruction to Improve Learning Comprehension in an Electrical Engineering Circuits Course

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Applying Problem-Solving Before Instruction (PS-I) to Improve Learning Outcomes and Engagement in an Electrical Engineering Circuits Course

1. Introduction and Background

The rigor and technical intricacies of engineering education can be challenging for many students. Successfully completing an engineering degree requires students to master theoretical concepts and complicated methodologies and learn how to implement them on complex real-world problems. In higher education, both students and instructors often feel time pressure due to the breadth and depth of material to be covered throughout the academic semester, compounded by the need to ensure that students graduate with a sound foundation of knowledge. These restrictions often lead to a reliance on Direct Instruction (DI) as a pedagogical approach, where instructors lecture and students passively listen. DI has a long-standing tradition of allowing instructors to take students through the complexities of the material, point to relevant features of the domain, and reduce floundering time on task [1]. Following this approach, traditional engineering courses often guide students through structured instruction before attempting to solve problems, which can limit opportunities for exploring the underlying complexity of concepts. In the recent decade and a half, however, DI was criticized for not scaffolding enough active learner engagement. This criticism was based on findings showing superior learning outcomes for active learning in comparison to DI, especially in STEM fields (Science, Technology, Engineering, and Mathematics; [2]–[4]).

One way to implement active learning in the classroom is using Problem-solving before Instruction (PS-I). PS-I is a pedagogical approach in which students first engage with challenging, ill-structured problems before learning the canonical solution [5], [6]. In this pedagogical approach, students often do not hold all relevant prior knowledge but are nonetheless required to try and solve complex problems relying on this knowledge. This process encourages active exploration, creative thinking, and resilience, as students must draw upon prior knowledge, make connections, and confront gaps in their understanding. This approach builds on the aim to Prepare learners for Future Learning (PFL;[7]–[9]) and considers failure at problem-solving as a catalyst for learning rather than a learning outcome on its own (also termed Productive Failure; PF [6], [10], [11]). Thus, PS-I emerged as a critical pedagogical approach in education, offering a robust framework for enhancing deep learning and problem-solving skills.

Notably, most PS-I or PF studies focused on middle-school students and the domain of mathematics. Furthermore, recent findings show that learning with PS-I pedagogy may lead to decreased performances on tasks requiring procedural knowledge but improves performances on inference and transfer assignments [5]. Thus, when thinking about training future engineers who will run into ill-structured problems, using PS-I may benefit them in the long run as it emphasizes preparation for future learning instances, even if that means failing in the short term. Given the potential advantages for engineering education, this study explores the potential benefits for this understudied population.

Here, we present a teaching intervention aimed at improving learning outcomes and engagement in an electrical circuits course (n=165) at an Electrical and Computer Engineering faculty by utilizing the concept of *Problem-solving before Instruction* during an applied module on transients in second-order electrical circuits. Up to the presented activity, while DI has been the sole teaching methodology, students' feedback reflected the unit to be more of a mathematical technical challenge, rather than an additional circuit theory insight. The intervention, which targeted a specific learning module of the whole course, had students work in groups to solve open-ended circuit analysis problems utilizing differential equations before receiving formal guidance on solution methods. Notably, while students took a prerequisite course on differential equations, the challenge in this module was the implementation in an electric circuits context. The intent was to engage students in deeper cognitive processes as they attempted to solve the problems based on prior knowledge of circuits analysis, calculus, and physics. Following this productive struggle, targeted instruction on second-order time dynamics in circuit analysis was delivered via fully recorded lecture and in-class tutorial lesson, completing theory as a whole, to the challenges students had encountered.

The guiding research question is as follows: To what extent does *Problem-Solving before Instruction improve student learning outcomes, students' perception of the activity, and their engagement?*

2. Method

2.1 Overview

This study presents a teaching intervention implementing PS-I through an in-class team-based activity (PS-I intervention) that is aimed at improving learning outcomes and engagement in the course *Electric Circuit Theory* delivered by the Electrical and Computer Engineering faculty.

To evaluate the impact of the PS-I intervention on students' learning outcomes and experience, three types of data were collected: (1) classroom observation, (2) student survey, and (3) an analysis of final exam scores.

2.2 Participants and Academic Context

The course in which the study took place is *Electric Circuit Theory*. It is a compulsory, 4-credit, advanced course for sophomore electrical and computer engineering students. The course provides students with knowledge and skills in fundamental topics, including lumped circuit analysis, transient responses, frequency domain analysis, and nonlinear circuits. This knowledge and skills should serve students in further courses dealing with electronic devices as well as analog and digital electronic circuits. It requires several pre-requisite courses (mainly ordinary differential equations and physics-2 - covering electricity and magnetism). The course lasts 13 weeks, with three weekly hours of lectures, two hours of tutorials, and supplementary hands-on workshops on circuits computer aid simulation tool (SPICE).

The intervention was implemented during the Spring 2024 semester. A total of 165 engineering undergraduates were enrolled in the course (42% women). Active participation, attendance, and Learning Management System (LMS) submissions were graded so students had a participation incentive.

2.3 Teaching Intervention

The PS-I intervention took place in week 7. The intervention included a 90-minute group activity embedded in the course's LMS. See the supplemental resource here: https://osf.io/s8gcb/?view_only=e0e9d577502f4925b14b2fac70c6efb4. Due to space limitations, the class was divided into two groups (n=~80 per group). Students registered to self-defined teams of 3-4 students via the LMS. Table 1 shows the course's grading rubric on the semester with the intervention and on a typical semester before the intervention. Figure 1 is a flowchart of the week 7 learning module.

After a short introduction by the teaching staff, students started working on a self-paced online quiz-like activity on their laptops in groups of 3-4. The activity was structured as a linear set of assignments. Teams could repeat the submission of each exercise until achieving success before progressing to the next one. The teaching assistants and instructor were in the classroom to guide students and answer questions.

Figure 1. Week 7 learning module.

Table 1. Course Grading Rubric

	Exam	Standard Homework	Computer-Aided Analysis Homework	Week 07 group work	Lecture 07 online video embedded quizzes
Pre-intervention	76%	12%	12%	0%	0%
Intervention	70%	12%	12%	3%	3%

The activity was designed based on pre-defined learning goals. These aimed to grant students with initial insights into the physical effects and were:

1. Recollection of basic mathematical procedures of solving second-order linear differential equations, and the expected various solutions and their functional nature.
2. Identifying and quantifying the initial stored energy at reactive components.
3. Identifying continuity or discontinuity of voltages and currents of those initial conditions when applying an abrupt external source change.
4. Understanding how the already known electrical laws facilitate the dynamics of a circuit composed of two reactive components in the form of a second-order differential equation.

5. Recognizing the need for constructing the response from both initial state response (ZIR) and forced response when external sources are applied (ZSR), as was already shown for first-order circuits.
6. Understanding the basic oscillating nature of energy resonating within an un-damped LC circuit.
7. Identifying the meaningful features or values that determine the various optional dynamic responses of the circuits, the related damping nature, and how that can be altered, in unique cases.

It is important to distinguish the above-mentioned learning goals from the topics traditionally covered by lectures:

1. Solving a canonical case of a serial RLC circuit, as only initial energy is stored in the circuit, without additional voltage or current sources.
2. Reviewing four possible responses (undamped, under-damped, critical damped, and over-damped), the typical time constants, the parameters governing those, and the overall time-dependent functional nature of each response.
3. Identifying the role of initial stored energy as response's initial conditions.
4. Addressing again the same circuit when only an abrupt voltage step is applied as an external source and formulating the forced response. Present it in adjunct to the already shown natural functional response of four distinct damping options.
5. Formulating the overall response of that circuit.

2.4 Data Collection and Analysis

The following data collection and analysis procedures were employed to evaluate the impact of PS-I on students' engagement and learning outcomes:

1. We conducted two classroom observations following the Classroom Observation Protocol for Undergraduate STEM (COPUS; [12]). This protocol records the activities during class time by students ("what students are doing") and the instructor ("what the instructor is doing"). It does so by documenting the activities taking place in 2-minute intervals. This protocol allows the non-judgmental quantification of classroom pedagogies. The first observation was done during the activity and the second during the following week, in a regular lecture-based session.

2. In addition, students completed a 5-point Likert scale survey following the intervention asking about their perceived learning experience.

3. Finally, learning outcomes were assessed via a paired sample t-test comparing students' outcomes on the final exam and comparing test items relating to the activity with those relating to the rest of the course.

3. Results

3.1 Student Survey

The survey focused on three main aspects of teaching and learning in the context of the activity: (1) The contribution of the activity with respect to the pre-set learning goals for the intervention, (2) the structure of the activity, and (3) the contribution of the activity to their learning.

Figure 2 shows that for all pre-set learning goals, at least 50% of 52 survey respondents reported the activity helped to a very great or a great extent. In fact, on most items, only ~20% of respondents reported the activity did not help them at all. The one exception is understanding the relationship between undamped oscillations and resonance frequencies, where fewer students reported the activity helped. This is likely the result of how the PS-I activity did not cover the full mathematical linkage of this phenomenon.

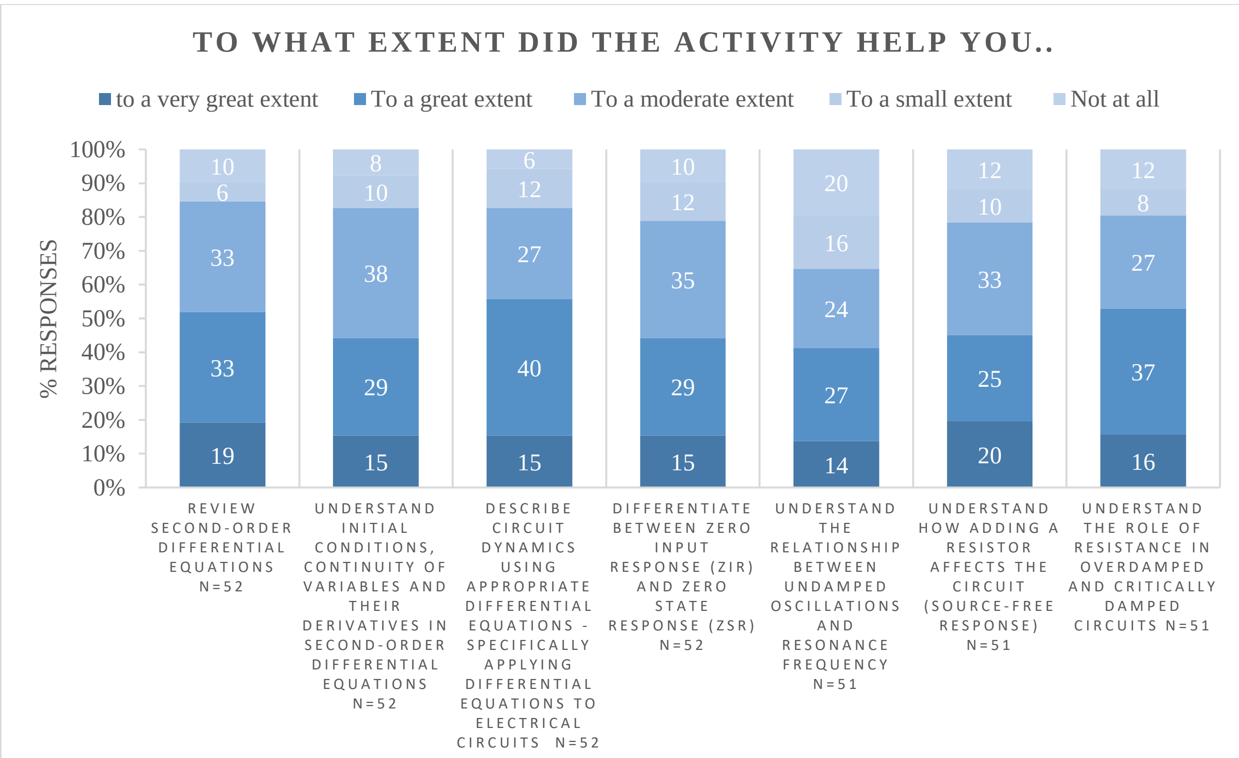

Figure 2. The contribution of the activity to the achievement of pre-set learning goals

Figure 3 shows students' feedback regarding the structure and content of the activity; 5 = Strongly Agree and 1 = Strongly Disagree. As seen in the figure, the lowest weighted averages were for items "I had enough time to complete the activity with the required depth." and "I felt I needed more mathematical background to complete the activity." These values can likely be attributed to a technical glitch (temporary lack of WIFI coverage), many students in the first round of the activity felt they did not have enough time to complete it. The highest weight average was for the items "The course staff were available for feedback and help during the activity." and "It helped that I could work with other people.". Both of these statements imply a supportive environment due to teamwork and teaching staff availability.

Survey Item	Weighted Average
It was clear to me how to progress from stage to stage and what I needed to do.	3.56
I think the activity was well-structured.	3.34
It helped that I could work with other people.	3.96
I had enough time to complete the activity with the required depth.	2.6
I felt I needed more mathematical background to complete the activity.	2.78
The course staff were available for feedback and help during the activity.	4.42

Figure 3. The structure of the activity

Figure 4 points to students' overall positive learning experience – 50% of 48 respondents reported the material covered was clear, almost 70% felt they had the opportunity to get answers to their questions, 55% followed the lesson and activity easily, and 49% reported they worked effectively and productively.

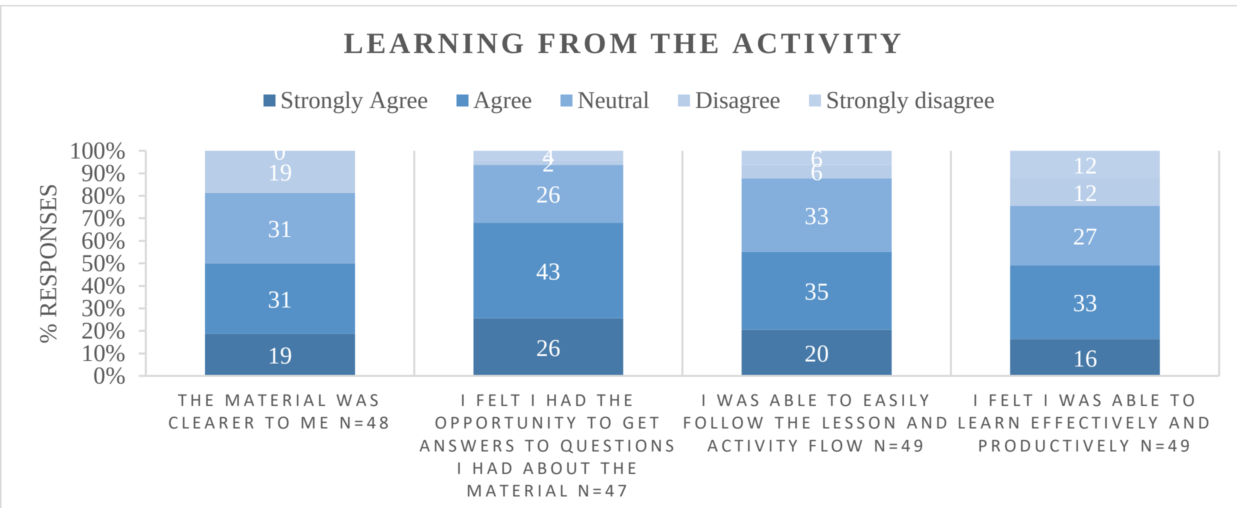

Figure 4. Overall learning experience

Survey results demonstrate that the activity yielded a positive learning experience for most students. Regarding students' frustration, other than that technical WIFI glitch that resulted in not having enough time allocated for the activity, it seems students were prepared to a good enough extent to cope positively with the problems and that the teaching staff provided enough support in the process.

3.2 Learning Outcomes

A total of 109 students took the final exam (out of 165 enrolled students). The exam included 24 multiple-choice questions. Out of the 24 questions, three evaluated the learning goals addressed by the activity. A paired-sample t-test compared the mean of the three items and the mean of the other items. We found a difference approaching (but not reaching) statistical significance favoring the activity items with a small effect size: $t(108) = -1.62$, $p = 0.054$, *Cohen's* $d = 0.28$

(*upper CI* = -0.34, *lower CI* = 0.03). See Table 2 and Figure 5 for the grade distribution of both types of items.

As seen in Figure 6, students' performances on the different exam components have a different distribution: On items not relating to the activity, there is a close to normal distribution while the activity-related distribution shows a left tail with more students scoring the maximum score on these items. These findings demonstrate a trend for the improvement of learning outcomes, despite not reaching statistical significance.

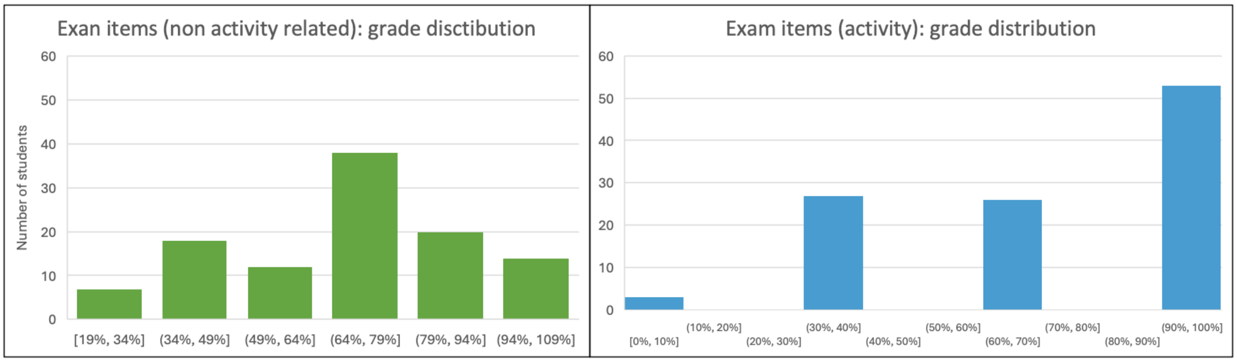

Figure 5. Learning outcome distribution on activity-related and non-activity-related items.

Table 2. Learning outcomes (exam)

	Exam items (non-activity)	Exam items (activity)
Mean (100-point scale)	68.37	72.78
SD	20	30

4. Discussion and Conclusions

4.1 Summary

In this study, we implemented and evaluated a PS-I pedagogy with sophomore undergraduate engineering students. Preliminary results reveal that PS-I led to higher levels of conceptual understanding and problem-solving ability compared to the content covered in the other, lecture-based teaching modules. Further, students reported a positive learning experience, emphasizing the contribution of the close interaction with the teaching staff as well as the opportunity to engage in hands-on problem-solving activities.

These findings indicate that PS-I can be an effective pedagogical approach for enhancing comprehension of complex engineering topics, particularly where mathematical modeling and real-world application intersect. This approach encourages active learning, promotes resilience in problem-solving, and leads to a deeper grasp of both the mathematical and dynamic behavior of electrical circuits.

Yet, while Problem-Solving Before Instruction (PS-I) enhances conceptual understanding by encouraging students to struggle with problems before receiving direct instruction, structured practice and guided problem-solving exercises can serve as critical complements to maximize learning outcomes. These additional elements help reinforce key concepts, bridge gaps in understanding, and provide scaffolding to ensure students fully benefit from the PS-I approach.

4.2 Limitations

While these initial findings are encouraging, some limitations apply. First, only a third of all students registered for the course (n=165) responded to the survey. This may limit the possibility of inferring on the entire class as this could suggest a bias in responses (e.g., only those who finished on time answered the survey). Future replications could help address this potential bias. Furthermore, as per the institution's test-taking policy, students could take the exam on a second occasion. As only two-thirds of all students registered for the course took the final exam on the first available attempt, the analysis does not include those who did so on a second attempt. It may be that the second exam attempt yielded a different grade distribution.

However, our findings nonetheless provide a useful snapshot into the successful implementation of a pedagogical approach that may lead to short-term failure or frustration but has the potential to improve students' ability to solve complex problems in the long term and real-world contexts.

4.3 Long-Term Scalability and Implementation Challenges of PS-I

The Problem-Solving Before Instruction (PS-I) approach has demonstrated benefits in fostering deeper learning and conceptual understanding within a single course. However, scaling this approach across multiple engineering courses and different learning environments presents several challenges that must be addressed for broader adoption. Below are key considerations related to long-term scalability and implementation challenges.

First, there are challenges with integration into other engineering courses. Engineering courses vary widely in content, complexity, and required foundational knowledge. While PS-I may work well in conceptually rich topics like electrical circuits, its effectiveness in highly computational courses (e.g., numerical methods) requires further study. In addition, many engineering faculty members are accustomed to traditional lecture-based teaching. Implementing PS-I would require professional development to help instructors design effective problem-solving activities and manage classroom dynamics. Finally, it is important to keep in mind that PS-I should align with accreditation requirements (e.g., ABET) and institutional learning outcomes. Ensuring consistency across courses without disrupting the broader curriculum is a challenge.

Second, considerations should be made for the long-term sustainability of implementing PS-I. Demonstrating the effectiveness of PS-I beyond a single course is crucial to gaining widespread faculty support. Providing evidence-based best practices and training opportunities can encourage adoption. Also, universities must invest in necessary infrastructure, such as classroom redesigns (for active learning) and digital tools (for online implementation), to support PS-I on a larger scale. Lastly, long-term data collection and iterative refinement are essential to assess PS-I's effectiveness across diverse student populations and learning contexts.

In conclusion, while PS-I offers promising benefits, its long-term scalability requires strategic planning, faculty development, and institutional support. Addressing challenges related to curriculum integration, large-class implementation, and online adaptation will enhance its impact and sustainability across engineering education.

References

[1] P. Kirschner, J. Sweller, and R. E. Clark, "Why unguided learning does not work: An Analysis of the Failure of Discovery Learning, Problem-Based Learning, Experiential Learning and Inquiry-Based Learning," *Educ. Psychol.*, vol. 41(2), pp. 75–86, 2006.

[2] M. T. H. Chi *et al.*, "Translating the ICAP Theory of Cognitive Engagement Into Practice," *Cogn. Sci.*, vol. 42, no. 6, pp. 1777–1832, 2018, doi: 10.1111/cogs.12626.

[3] S. Freeman *et al.*, "Active learning increases student performance in science, engineering, and mathematics," *Proc. Natl. Acad. Sci. U. S. A.*, vol. 111, no. 23, pp. 8410–8415, 2014, doi: 10.1073/pnas.1319030111.

[4] J. Hattie, *Visible learning: A synthesis of over 800 meta-analyses relating to achievement*. 2008.

[5] K. Loibl, I. Roll, and N. Rummel, "Towards a Theory of When and How Problem Solving Followed by Instruction Supports Learning," *Educ. Psychol. Rev.*, vol. 29, no. 4, pp. 693–715, 2017, doi: 10.1007/s10648-016-9379-x.

[6] T. Sinha and M. Kapur, *When Problem Solving Followed by Instruction Works: Evidence for Productive Failure*, vol. 91, no. 5. 2021.

[7] J. D. Bransford and D. L. Schwartz, "Rethinking transfer: A simple proposal with multiple implications," *Rev. Res. Educ.*, vol. 24, pp. 61–100, 1999, doi: 10.3102/0091732x024001061.

[8] D. L. Schwartz, J. D. Bransford, and D. Sears, "Efficiency in Innovation and Transfer," *Transf. Learn. from a Mod. Multidiscip. Perspect.*, pp. 1–51, 2005.

[9] D. L. Schwartz and T. Martin, "Inventing to Prepare for Future Learning: The Hidden Efficiency of Encouraging Original Student Production in Statistics Instruction," *Cogn. Instr.*, vol. 22, no. 2, pp. 129–184, Jun. 2004, doi: 10.1207/s1532690xci2202_1.

[10] M. Kapur, "Productive Failure in Learning Math," vol. 38, pp. 1008–1022, 2014, doi: 10.1111/cogs.12107.

[11] M. Kapur and N. Walk, "Productive Failure," no. 1995, pp. 307–313, 2006.

[12] M. K. Smith, F. H. M. Jones, S. L. Gilbert, and C. E. Wieman, "The classroom observation protocol for undergraduate stem (COPUS): A new instrument to characterize university STEM classroom practices," *CBE Life Sci. Educ.*, vol. 12, no. 4, pp. 618–627, 2013, doi: 10.1187/cbe.13-08-0154.