



Linking Introductory Physics to Professional Practice: A Project-Based Challenge for Biotechnology and Chemical Engineering Students

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Abstract

Introductory physics courses for engineering students often face difficulties in promoting engagement and perceived relevance, particularly when abstract electrical concepts are taught without clear connections to professional practice. This paper reports the design and early evaluation of an innovative challenge-based learning project implemented in a first-year introductory physics course on electricity for biotechnology and chemical engineering students. The intervention was delivered as a five-week intensive multi-instructor course organized into three integrated modules: Physics, Computational Methods, and a Challenge module which included a so-called field instructor to contextualize the project within students' professional domains. The course challenge consisted of designing, building, calibrating, and validating a low-cost conductimeter based on a Kohlrausch bridge configuration, reported in the literature, using readily available components. Students applied the instrument to measure the conductivity of fruit and vegetable extracts and to monitor conductivity changes during a chemical reaction, linking physics concepts to applications relevant to biotechnology and chemical engineering. A mixed-methods evaluation was conducted with 34 students using a post-project questionnaire combining Likert-scale items and open-ended questions.

Quantitative results indicate high perceived relevance of the project to the Physics module and strong agreement regarding learning new things, with over 77% and 90% of students reporting high to total relevance and agreement, respectively. Importantly, more than 65% of students reported moderate to total perceived connection with their college degrees. Qualitative analysis revealed that circuit construction constituted a major challenge but was also perceived as one of the most rewarding aspects of the experience, suggesting the presence of productive struggle. On the other hand, computational tasks, particularly MATLAB-based analysis, were identified as a significant barrier for some students. All in all, these early findings provide substantial guidance on the challenge project design for future implementation.

Keywords: Challenge-Based Learning; Engineering Education; Physics Education; Student Engagement; Curriculum Design.

1. Introduction

Introductory physics courses for engineering students frequently struggle to balance conceptual rigor with professional relevance. Moreover, topics such as electric circuits, resistance, and conductivity have been long known to be particularly difficult to understand and prone to multiple misunderstandings due to their non-intuitive and sometimes abstract nature [1,2,3]. Unfortunately, these topics are often presented through traditional expository lectures and abstract problem-solving exercises that students perceive as disconnected from their future practice, particularly in disciplines such as biotechnology and chemical engineering. However, the negative effect of this perceived misalignment can be successfully addressed by incorporating more well-thought-out activities and lab projects to render the course more relevant to the students' fields of major [4].

To address this challenge, particular project-centered pedagogies such as Challenge-Based Learning (CBL) have gained attention for their potential to situate disciplinary knowledge within authentic, real-world contexts [5,6,7,8]. By engaging students in the design and implementation of tangible solutions, these approaches aim to foster motivation, interdisciplinary integration, and the development of professional competencies. However, implementing such strategies in first-year courses remains challenging due to limited student experience, time constraints, and the cost of laboratory equipment.



This paper presents the design and early evaluation of a challenge-based project implemented in a first-year introductory physics course on electricity for biotechnology and chemical engineering students. The project centers on the construction and application of a low-cost conductimeter, reported in the literature [9], using accessible components, allowing students to engage directly with core physics concepts while exploring applications relevant to their disciplines.

Given the exploratory nature of the intervention and the modest sample size, this study is framed as a Work In Progress. Rather than measuring learning gains, the evaluation focuses on students' perceptions of relevance, engagement, and conceptual support, as well as their qualitative feedback regarding challenges and valued aspects of the project.

2. Educational Context And Course Design

The intervention was implemented within the Tec21 educational model, an institutional framework that emphasizes Challenge-Based Learning, flexibility, and the development of professional and transversal competencies through immersive, real-world problems [10,11]. Courses are delivered in intensive "block" formats that integrate disciplinary knowledge with applied challenges.

The physics course analyzed in this study was offered as a five-week block totaling 60 hours and organized into three coordinated modules: Physics, Computational Methods, and Challenge. Instruction followed a team-teaching model involving four instructors: a physics instructor, a computational methods instructor, a challenge instructor, and a field instructor. The field instructor played a central role in linking the project activities to professional applications in biotechnology and chemical engineering.

The challenge project consisted of designing and building a low-cost conductimeter based on a Kohlrausch bridge configuration. Students constructed the device using basic electronic components, calibrated the instrument by determining the cell constant with standard solutions, and validated their measurements against a Vernier educational conductimeter. The project culminated in two applied activities: measuring the conductivity of fruit and vegetable extracts, and monitoring conductivity changes during a chemical reaction, as proposed in [9,12]. These activities were explicitly connected to professional practices in food analysis and chemical process monitoring.

Physics topics engaged through the project included Ohm's Law, electrical resistance and resistivity, electric current, conductivity, Kirchhoff's laws, and circuit analysis. Computational methods were introduced to estimate the dielectric constant of water using MATLAB and the Debye–Hückel–Onsager equation [13].



Fig.1. Student Conductimeter Prototype. Completed student conductimeter prototype (left) with all main elements at sight: AC transformer (1), electrochemical cell (2), and the perfboard on which the Kohlrausch bridge was implemented (3). Students testing another conductimeter prototype with a power drink (right).

3. Methods

3.1 Context and Participants

The study was conducted in a first-year introductory Physics block course on electricity offered to biotechnology and chemical engineering students within the Tec21 educational model. The block had a duration of five weeks (60 hours) and was organized into three interconnected modules: Physics,



Computational Methods, and Challenge. Instruction followed a team-teaching format involving four instructors: a physics instructor, a computational methods instructor, a challenge instructor, and a field instructor responsible for linking the project with professional applications in biotechnology and chemical engineering.

A total of 34 students enrolled in the course participated in the evaluation. Participation in the questionnaire was voluntary and took place after completion of the challenge project and final presentations.

3.2 The Challenge Project

Students designed and built a low-cost conductimeter based on a Kohlrausch bridge configuration using readily available components: resistors, a small transformer, and carbon electrodes (see Fig.1). The project involved:

1. constructing and wiring the circuit,
2. constructing the cell and calibrating the cell constant with standard solutions,
3. validating measurements against a Vernier educational conductimeter, and
4. applying the instrument to two contexts: conductivity of fruits and vegetables and monitoring a chemical reaction.

The challenge was designed to integrate core physics topics (Ohm's law, resistance, current, circuit analysis) and computational procedures implemented in MATLAB for estimating the dielectric constant using the Debye–Hückel–Onsager equation.

3.3 Data Collection Instrument

Student perceptions were gathered through a digital questionnaire composed of closed and open-ended items. Table 1 summarizes the questionnaire items and the Likert anchors used.

Closed questions used five-point Likert scales to evaluate:

- Perceived relevance of the challenge to the Physics module, Computational Methods module, and college degree (Q1-Q3, Table 1);
- Engagement and perceived learning, including interest in the project, usefulness for understanding physics, and learning new things (Q4-Q6, Table 1).
- Physics concepts better understood through the challenge (Table 2).

Construct	Item (English translation)	Response Scale
Relevance to degree	Q1. How related is the challenge project to your college degree?	1=None, 2=Slightly related, 3=Moderately related, 4=Highly related, 5=Totally related
Relevance to Physics	Q2. How related is the challenge project to the Physics module?	1=None, 2=Slightly related, 3=Moderately related, 4=Highly related, 5=Totally related
Relevance to Computational Methods	Q3. How related is the challenge project to the Computational Methods module?	1=None, 2=Slightly related, 3=Moderately related, 4=Highly related, 5=Totally related
Engagement	Q4. I find the challenge project interesting	1=Strongly disagree, 2=Disagree, 3=Neutral, 4=Agree, 5=Strongly agree
Perceived usefulness (Physics)	Q5. The challenge project was useful to better understand the Physics module topics	1=Strongly disagree, 2=Disagree, 3=Neutral, 4=Agree, 5=Strongly agree
Perceived learning	Q6. The challenge project allowed me to learn new things	1=Strongly disagree, 2=Disagree, 3=Neutral, 4=Agree, 5=Strongly agree

Table 1. Questionnaire items and Likert-scale anchors. Closed items used to evaluate perceived relevance, engagement, and learning in the challenge project. Response scales ranged from 1 to 5. Items were originally administered in Spanish and are reported here in English translation.



Open-ended questions invited students to describe: their **biggest struggle** during the project, what they **liked best**, and what they **liked least**.

3.4 Data Analysis

Quantitative data was analyzed using descriptive statistics. Response distributions were visualized through bar charts comparing perceived relevance across modules (Fig. 2) and indicators of engagement and perceived learning (Fig. 3). Frequencies for physics concepts supported by the challenge were ranked and reported in Table 2.

Open-ended responses were examined through an inductive thematic synthesis appropriate for a Work In Progress study [14]. Responses were read iteratively, initial codes were generated capturing difficulties, valued aspects, and design critiques, and codes were grouped into broader themes reflecting recurrent patterns across participants. The analysis aimed to inform course redesign rather than to achieve formal qualitative saturation.

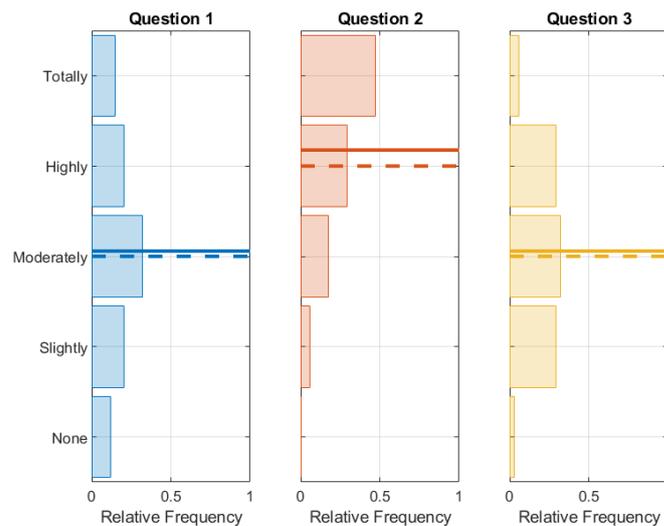


Fig.2. Perceived relevance of the challenge project to different course dimensions. Comparison of student ratings regarding the relationship between the challenge project and the Computational Methods module (Question 3), the Physics module (Question 2), and their college degree (Question 1). Values represent the relative frequency of responses in each Likert category (1=None to 5=Totally related). The median and mean values for each question are also shown as a horizontal dashed and solid line, respectively.

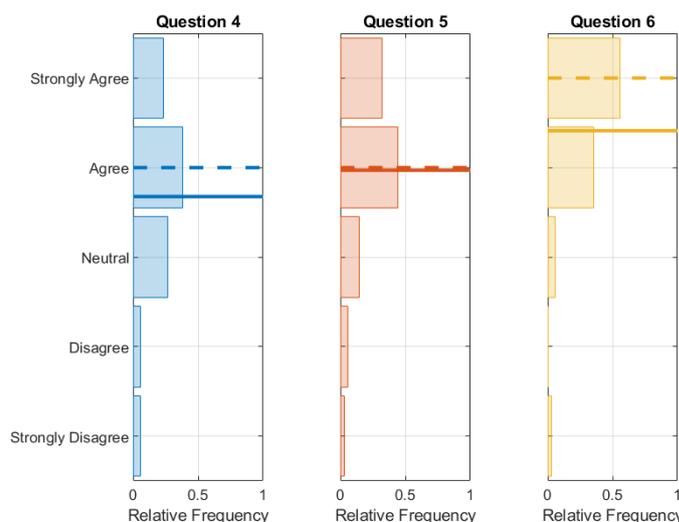


Fig.3. Engagement and perceived learning associated with the challenge project. Student agreement with statements on interest in the project (Question 4), usefulness for understanding Physics topics (Question 5), and learning new things (Question 6). Values represent the relative frequency of responses on a five-point Likert scale (1=Strongly disagree to 5=Strongly agree). The median and mean values for each question are also shown as a horizontal dashed and solid line, respectively.



4. Results

4.1 Perceived Relevance of the Challenge

Students' perceptions of the project's relevance differed across the three course modules. The strongest alignment was reported with the Physics module, where 76.5% of students considered the challenge to be *highly* or *totally related*, and none selected the option "not related." In contrast, perceived relevance to the Computational Methods module was more moderate, with only 35.3% selecting *highly* or *totally related*, while 32.3% considered it only *slightly related*. Perceived connection with students' college degrees showed a broad distribution: 35.3% viewed the project as *highly* or *totally related*, 32.4% as *moderately related*, and 32.4% as *slightly* or *not related*.

These results suggest that the project effectively supported the intended integration with physics content, while the professional and computational connections were less transparent for a portion of the students.

4.2 Engagement and Perceived Learning

Overall engagement with the challenge was positive. A majority of students agreed that the project was interesting (61.7% agree/strongly agree) and useful for understanding physics concepts (76.5% agree/strongly agree). The most robust result concerned perceived learning: 91.1% of students agreed that the challenge allowed them to *learn new things*, with more than half selecting *strongly agree*.

When asked which physics concepts were better understood through the project, students predominantly selected topics directly involved in the construction and use of the conductimeter, whereas concepts with a more abstract character, such as electromotive force, were selected less frequently (see Table 2). This pattern indicates a close correspondence between hands-on activities and perceived conceptual understanding.

Concept	Proportion	Concept	Proportion
Ohm's Law	91.2%	Electrical Conductivity	67.7%
Calculation of Electrical Resistance	82.4%	Electric Potential	44.1%
Concepts of Electrical Resistance	79.4%	Electromotive Force	14.7%
Concepts of Electrical Current	76.5%		

Table 2. Physics concepts better understood through the challenge. Ranked frequency of physics topics that students reported as better understood as a result of the challenge project (N=34). Students could select multiple options; percentages represent the proportion of participants selecting each concept.

4.2 Student-Reported Challenges and Valued Aspects

Thematic analysis of open-ended responses revealed four recurrent themes.

Circuit construction as productive struggle: Building and troubleshooting the electrical circuit was the most frequently mentioned difficulty. Students referred to lack of prior experience, uncertainty when wiring components, and problems achieving a stable measurement. At the same time, the same activity appeared repeatedly as the *most valued* aspect of the project. Comments such as "when the conductimeter finally worked" and "although it was the hardest part, it was the most interesting" illustrate how difficulty coexisted with a strong sense of accomplishment. This dual perception positions circuit construction as a form of productive struggle that fostered engagement through authenticity.

Computational methods as a barrier: Work with MATLAB and the Onsager equation constituted a second major challenge. Many students reported not understanding the code, difficulties manipulating equations, or discomfort with graphical analysis. Unlike circuit construction, computational tasks were rarely described as enjoyable, indicating a potential mismatch between the level of computational abstraction and students' readiness in the first year.

Authenticity and experimentation as motivators: Students consistently valued the opportunity to build a real instrument, test different solutions, and compare their prototype with a Vernier device.



Activities such as measuring the conductivity of fruits and vegetables were highlighted as meaningful, reinforcing the experiential character of the challenge.

Need for greater scaffolding and alignment: Several responses pointed to fast pacing, limited guidance before construction, and perceived disconnection between some analytical tasks and the final application. These critiques were generally framed as implementation issues rather than rejection of the project concept.

5. Discussion

The results provide preliminary evidence that a low-cost, challenge-based conductimeter project can support engagement and perceived relevance in an introductory physics course for biotechnology and chemical engineering students. The high levels of agreement regarding the acquisition of new knowledge (referred as “learning new things” in the questionnaire) and usefulness for understanding physics suggest that the intervention succeeded in connecting abstract electrical concepts with tangible experience. The strong selection of Ohm’s Law and resistance-related topics confirms the constructive alignment between the project design and core disciplinary content.

5.1 Authenticity versus Difficulty

A central insight is the ambivalent role of circuit construction. Students’ narratives show that the same activity generated both frustration and motivation. From a design perspective, this tension is desirable: engineering education literature emphasizes that meaningful learning often occurs when students confront uncertainty and must iteratively debug physical systems [15]. The findings indicate that the project achieved this authentic character, even though first-year students had limited prior exposure to electronics.

5.2 The Computational Gap

In contrast, the computational component emerged as a weaker link. Lower perceived relevance to the Computational Methods module and frequent complaints about MATLAB suggest that this part of the challenge required cognitive resources that exceeded many students’ preparation. Rather than removing the computational element—which is essential for modern engineering practice—the results point to the need for progressive scaffolding, clearer integration with the experimental narrative, and possibly alternative pathways for students with different backgrounds.

5.3 Professional Relevance and the Role of the Field Instructor

Perceptions of relevance to students’ degrees were positive but more heterogeneous. Qualitative comments highlight the importance of contextual activities, such as measuring food products or monitoring a chemical reaction, where the field instructor explicitly linked physics concepts to biotechnology and chemical engineering practice. Strengthening these connections earlier in the block or exploring additional professional applications may increase the proportion of students who perceive the project as highly related to their profession.

5.4 Limitations

This study is exploratory and based on a small group of students (N=34) with self-reported perceptions. No pre/post conceptual tests were applied, and qualitative analysis was intentionally lightweight. Therefore, results should be interpreted as design feedback rather than evidence of learning gains.

6. Conclusions

This paper reported the design and early evaluation of a challenge-based project in a first-year introductory physics course on electricity for biotechnology and chemical engineering students. The intervention centered on building and applying a low-cost conductimeter to connect core physics concepts with computational methods and professionally relevant contexts. Student feedback indicates high engagement and strong perceived usefulness for understanding key physics topics. Perceived relevance to students’ major fields was generally positive, though heterogeneous,



highlighting the value of professional contextualization while indicating room for strengthening disciplinary alignment. Qualitative feedback highlights circuit construction as a central element of productive struggle, simultaneously challenging and motivating students through authentic engineering practices. In contrast, computational tasks revealed a need for additional scaffolding. As a Work In Progress, the study offers design-oriented insights that inform future improvements. The findings provide actionable insights for refining this challenge-based physics instruction, such as incorporating additional laboratory time for troubleshooting and orientation regarding the circuit, improved scaffolding for computational tasks, and strengthening strategies to enhance the perceived relevance of the challenge and course to the students' future professional domain.

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