Revolutionizing STEM Education with Artificial Intelligence in Technical and Vocational Education

A partnership between Lab4U and INACAP

Summary

Traditional teaching methods often fail to engage students and personalize their learning experiences. To address this issue, AI tools such as a customized STEM resource generator, formative assessments, and a virtual assistant were implemented in a pilot project with INACAP, a Chilean institution of higher technical education. The pilot results showed a significant 31% improvement in student grades and a 5 percentage point decrease in the failure rate. Additionally, student engagement increased due to the use of motivating, collaborative methodologies that promote hands-on learning. The project also led to a transformation in educational practices, resulting in the creation of 27 class resources and 73 assessment resources. Next steps include expanding tools like the Resource Generator, experimental tools, and quizzes to other subject areas, as well as evaluating their long-term impact on learning.

Introduction

In a world increasingly driven by technological innovation and digital transformation, the skills needed for future talent are becoming centered around critical thinking, problem-solving, and adaptability. However, there is a growing gap between the competencies demanded by the labor market and those developed by traditional education systems, particularly in key areas like STEM (Science, Technology, Engineering, and Mathematics). To bridge this gap, it is essential to reimagine how subjects like physics are taught, incorporating innovative methodologies that engage students and equip them with applicable, long-lasting skills.

Traditionally, physics education at both school and higher education levels has relied on passive teaching methods, such as lectures and summative assessments. Unfortunately, these approaches often fail to foster deep learning or support long-term knowledge retention and application. As education evolves, strategies like active learning and gamification have emerged to enhance students' learning experiences. Despite their advantages, these methodologies often face challenges in terms of implementation, scalability, and adaptation to individual learning needs.

Active learning, problem-based learning (PBL), and gamification have demonstrated promise in enhancing student engagement, fostering collaboration, and enhancing both conceptual and procedural understanding. Nevertheless, significant implementation challenges remain, including insufficient teacher training in new methodologies and resistance to change (Prince, 2004).

This paper argues that integrating active learning methodologies powered by Artificial Intelligence (AI) in physics instruction can transform both student learning and teacher teaching practices. AI enables the generation of personalized educational resources, provides real-time feedback, and enhances the learning experience through interactive tools. By developing the AI-powered Resource Generator for INACAP[1] and utilizing Lab4U tools, which leverage mobile device sensors to create innovative learning experiences, we explore how this innovation facilitates the teaching of Mechanical Physics in higher education, aligning content with the specific needs of each degree program.

Challenges and Opportunities in STEM Teaching

One of the major challenges in teaching science at the higher education level is the necessity for learning to be meaningful, specifically, relevant to students and their future professional contexts. Therefore, contextualizing learning is essential, requiring educators to put in extra effort to ensure that problems, exercises, and practical experiences, such as those in mechanics, are pertinent and valuable for students in fields like Mining, Automation, and Renewable Energy.

1 INACAP is a national institution in Chile that offers technical and professional higher education.

Solution

Once it was determined that using AI to generate active and contextualized teaching strategies would effectively address the institution's previously identified needs, four Lab4U tools were proposed:

Lab4U Experiences

Teachers and students gain access to over 70 pre-designed hands-on physics experiences, aligned with core topics in general physics, through the Lab4U App. These experiences promote practical learning and scientific inquiry through a five-step process: Think, Build, Measure, Analyze, and Conclude. This methodology, along with Lab4U's capability to collect real-time data using mobile device sensors, enhances scientific learning, democratizes access to experimentation, and helps reduce educational gaps in science.

Resource Generator for INACAP

This innovative digital tool employs AI to assist teachers in creating customized learning materials, including exercises, assessments, and activities. These resources are tailored to meet the specific needs of each degree program, ensuring that the content is relevant and aligned with learning objectives and competencies.

Among the AI-generated resources are contextualized practical experiences utilizing Lab4U tools and mobile sensors, enabling students to conduct experiments that enhance both their physics knowledge and scientific inquiry skills.

Quizzes

This Lab4U tool, integrated with the Resource Generator, allows teachers to automatically add formative assessment quizzes to their activities. Students can access the quizzes using a unique code and receive immediate feedback after each question. This feature enables them to track their progress in real-time.

TutorIA

TutorIA is a conversational virtual assistant designed to help students reinforce their understanding of Mechanical Physics. Through interactive chat, TutorIA provides exam-like questions along with clear and concise explanations for solving them.

Implementation

To evaluate the impact of active and contextualized educational experiences, a pilot program was conducted with students and instructors of the Mechanical Physics course over a span of five weeks. This program encompassed three academic areas—Automation and Robotics, Mechanics, and Mining—across seven INACAP campuses. The program involved:

1. Five "champion" teachers trained to support other teachers.

2. Five teachers participated in the pilot program in five study programs that include the subject of Mechanical Physics;.

3. A total of 251 students were impacted by the initiative.

Pilot Milestones and Progress

Table 1. Timeline Milestones During the Inacap-Lab4U Pilot

Month	Activity
January	Innovation focus areas
March - April	Platform development and customization
May	Instructors training
August	Instructor feedback
October	Pilot launch
November	Perception evaluation

Case Study

Promoting Active Learning and Formative Assessment

A platform was developed that utilizes AI to generate contextualized educational resources. This platform allows instructors to choose curricula and learning objectives specific to each degree program and create activities that correspond to the challenges students may face in their professional lives.

The system offers various types of personalized activities for INACAP, tailored to its educational model and graduate profiles:

- Lab4U Experiences: Hands-on activities using Lab4U tools that enable students to conduct and analyze experiments related to the Mechanical Physics course unit.
- Modeling: Problem-based learning activities customized for each program, which include stages such as materials and resources, guiding questions, result analysis, and more.
- Use of Technology: Activities designed to promote the integration of interactive digital tools to reinforce concepts in Mechanics.
- Quizzes: Integrated into the Resource Generator for assessing the knowledge gained from the designed activities.

Results

For this case, both quantitative and qualitative indicators were assessed, taking into account that they were gathered during the effective use of Lab4U in the classroom throughout the pilot program from October to December.

Quantitative Results

Coverage

100% of students were registered on the Lab4U platform and had access to the Lab4U App and its tools.

Usage Rate

100% of instructors created resources and assessments using the INACAP AI Resource Generator; 86% of them created two or more resources. In total:

- 27 class resources were generated, including Modeling, Technology Use, and Lab4U Experiences.
- Additionally, 73 quizzes were created, achieving an average student success rate of 71%.

Academic Performance[2]

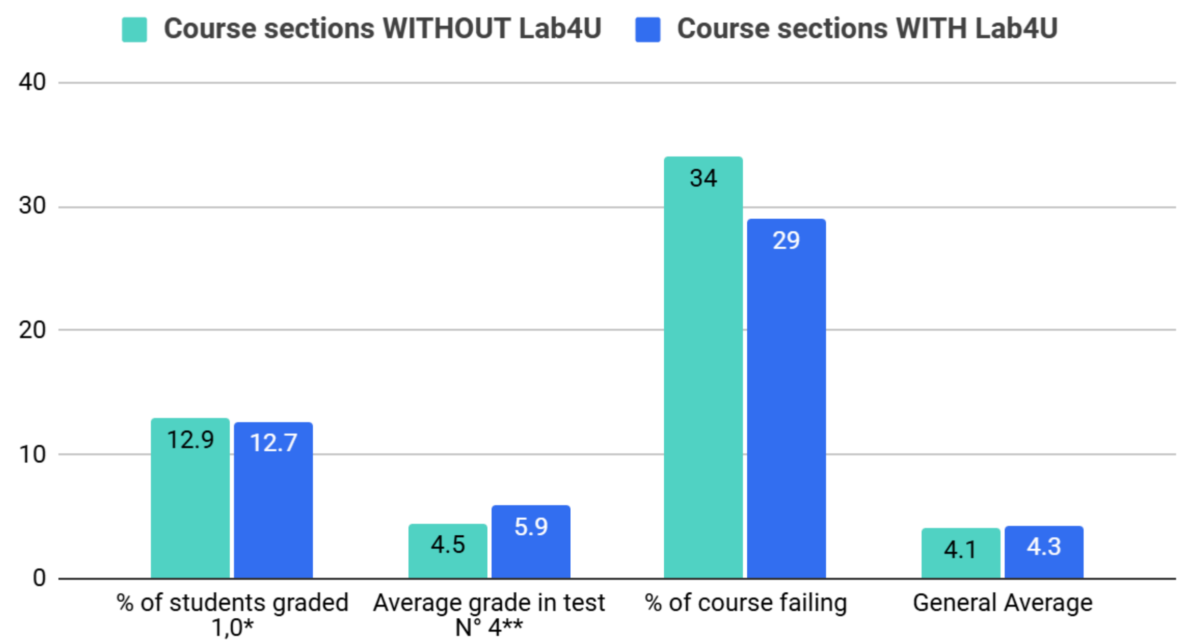
- **There was a 31% increase in the average grade** during the final unit assessment (Assessment 4).
- **Increase in the overall average** grade in the targeted courses by 0.2 points.
- **Reduction in the failure rate** by 5 percentage points.

Table 2. Difference in student performance with and without Lab4U.

Criteria	Courses WITHOUT Lab4U*	Courses WITH Lab4U**
% of grade 1,0	12,9%	12,7%
Average Assesment N°4	4,5	5,9***
% of failure	34%	29%***
General Average	4,1	4,3***

*207 students using Lab4U - **617 students without Lab4U. *** Results achieving the proposed KPIs

Chart 1. Performance comparison between sections using and not using Lab4U.



Given that the Mechanical Physics course included four assessments[2], a statistical analysis was conducted to determine the significance of the results:

Table 4. Statistical analysis of Assessments 1, 2, and 3.

Variable	Assessment 1		Assessment 2		Assessment 3	
	Difference in means	¿Meaningful?	Difference in means	¿Meaningful?	Difference in means	¿Meaningful?
Average	-0.126	No	-0.084	No	-0.295	No
Average without 1.0 grades	-0.118	No	0.232	No	-0.123	No
% of 1.0 grades	0.003	No	0.013	No	0.012	No

***Difference in means** = (Measured with intervention) - (Measured without intervention)

[2] In this study, there are 207 students who used Lab4U and 617 students who did not use Lab4U.

Tabla 5. Statistical analysis of Assessment 4.

Variable	Assessment 4		
	Difference in means	p-value	¿Meaningful?
Average	0.871	0.019	Yes
Average without 1.0 grades	1.256	0.001	Yes
% of 1.0 grades	-0.013	-0.013	No

*Difference in means = (Measured with intervention) - (Measured without intervention)

**A significant p-value in a difference of means indicates that the observed difference is statistically significant, meaning it is unlikely to be due to chance. A numerical value of 0.05 or less is typically considered statistically significant.

From Table 4, we conclude that there were no significant differences between groups for Assessments 1 to 3. In contrast, Table 5 shows a statistically significant improvement in the Lab4U group for Assessment 4.

Qualitative Results

During the implementation, Lab4U provided ongoing support through surveys, feedback sessions, and evaluations of both methodology and platform. This collaborative approach ensured alignment with instructors' needs and teaching practices.

According to survey responses, teachers reported several benefits, including increased student motivation and collaboration. They noted improved grades and appreciated how Lab4U facilitated the integration of hands-on learning.

Students expressed a significant increase in interest in the course, highlighting that AI helped them solve complex problems, thereby improving their understanding and application of physics concepts. 4.1 out of 5 students expressed a desire for more active and practical learning opportunities with Lab4U, which they felt helped them learn more effectively.

Benefits and Impact

The integration of technology in STEM education has demonstrated significant benefits across various dimensions. The Resource Generator is a standout tool that automatically creates personalized learning materials aligned with INACAP's instructional guidelines, enhancing content relevance for students.

Tools like Quizzes enable instructors to design formative assessments that provide automated and immediate feedback to students through their mobile devices. This timely feedback helps identify areas for improvement and allows students to refine their study strategies. Additionally, the virtual assistant TutorIA enhances self-directed learning by enabling students to practice Mechanics at their own pace, fostering academic independence and self-regulation.

Together, these tools, along with positive quantitative results, confirm the beneficial impact of this technological integration, illustrating significant improvements in academic performance and reductions in failure rates.

The personalized and interactive nature of Lab4U resources has led to increased student engagement and motivation in learning physics. For instructors, the automation of resource and assessment creation saves valuable time, allowing them to concentrate more on student interaction and strategic lesson planning.

Finally, one of the most promising aspects of these AI-based tools is their scalability, making them suitable for widespread use in physics education across large populations of students and teachers. This feature is particularly valuable in educational contexts seeking to expand their reach without compromising the quality of the learning experience.

In general, the use of AI in education has the potential to transform the way physics is taught and learned, making it more contextualized, interactive, and effective.

Conclusion

The integration of AI tools—such as the Resource Generator, Quizzes, and TutorIA—into physics education has proven to be an effective solution for the challenges of traditional instruction, especially in higher education. By contextualizing learning, providing immediate feedback, and promoting active student engagement, these tools enhance understanding of physics phenomena, improve academic outcomes, and reduce failure rates.

The pilot conducted with INACAP supports the transformative potential of AI in physics education, offering a scalable and adaptable approach that meets the needs of diverse institutions and academic programs. Improvements in student performance, reduced dropout rates, and increased engagement all highlight the positive impact of these tools.

The success of this initiative suggests that integrating AI in education is not only feasible but also necessary to prepare students for the future. Expanding these tools to other areas and continuing to innovate in AI promises a future where education is more effective, personalized, and accessible to all.

These results not only impact physics teaching but also suggests that AI has the potential to transform education as a whole, making it more effective, personalized, and inclusive across all STEM disciplines.

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