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Enhancing Structural Engineering Education: Integrating Artificial Intelligence for Continuous Improvement

Mejora Continua en la Educación de Ingeniería Estructural: Aplicación Práctica del uso de Inteligencia Artificial

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Abstract

The study aims to analyze the impact of artificial intelligence (AI) usage on structural learning through student-developed programming in open-source software languages: Python, Octave, and OpenSees. The research collaborates with 90 undergraduate students in the early courses of civil engineering at the Universidad Nacional de Chimborazo. The ADDIE methodology is employed in the initial phase for planning, development, and monitoring. A survey on students' perceptions regarding effectiveness, satisfaction, recommendation, and feedback is conducted, followed by academic performance evaluation using a grading rubric to verify the achievement of set objectives. An analysis of factors contributing to AI-focused learning is then performed. Initial results revealed outliers, some deviating from study parameters and others discarded for a comprehensive view of study behavior. Regarding the survey data analysis, efficiency and satisfaction exhibited the highest reliability. Subsequently, variables were correlated considering their normality, showing a relationship between effectiveness and satisfaction; however, a strong connection cannot be guaranteed for these or other variables. Therefore, ANOVA tests, indicating positive linear relationships, and hypothesis testing were employed, demonstrating that students achieved objectives with a moderately high degree of effectiveness and satisfaction. The use of technological options and consideration of innovative learning methods can positively enhance the learning experience, contingent on prior education. Exploring artificial intelligence may prove challenging without guided information search based on predefined criteria and constraints.

Keywords: Artificial intelligence, Artificial intelligence in education, STEM education, General system theory, educational system

Resumen

El estudio pretende analizar el impacto del uso de la inteligencia artificial (IA) en el aprendizaje estructural a través de la programación desarrollada por los estudiantes en lenguajes de software de código abierto: Python, Octave y OpenSees. En la investigación colaboran 90 estudiantes de pregrado de los primeros cursos de ingeniería civil de la Universidad Nacional de Chimborazo. Se emplea la metodología ADDIE en la fase inicial para la planificación, desarrollo y seguimiento. Se realiza una encuesta sobre las percepciones de los estudiantes en cuanto a efectividad, satisfacción, recomendación y retroalimentación, seguida de una evaluación del desempeño académico utilizando una rúbrica de calificación para verificar el logro de los objetivos planteados. A continuación, se realiza un análisis de los factores que contribuyen al aprendizaje centrado en la IA. Los resultados iniciales revelaron valores atípicos, algunos desviados de los parámetros del estudio y otros descartados para obtener una visión global del comportamiento del estudio. En cuanto al análisis de los datos de la encuesta, la eficiencia y la satisfacción mostraron la mayor fiabilidad. Posteriormente, se correlacionaron las variables teniendo en cuenta su normalidad, mostrando una relación entre la eficacia y la satisfacción; sin embargo, no se puede garantizar una conexión fuerte para estas u otras variables. Por lo tanto, se emplearon pruebas ANOVA, que indicaron relaciones lineales positivas, y pruebas de hipótesis, demostrando que los estudiantes alcanzaron los objetivos con un grado moderadamente alto de eficacia y satisfacción. El uso de opciones tecnológicas y la consideración de métodos de aprendizaje innovadores pueden mejorar positivamente la experiencia de aprendizaje, en función de la formación previa. La exploración de la inteligencia artificial puede resultar difícil sin una búsqueda guiada de información basada en criterios y restricciones predefinidos.

Palabras clave: Inteligencia artificial, Inteligencia artificial en la educación, educación STEM, Teoría general de sistemas, sistema educativo

Introduction

In the realm of education within Science, Technology, Engineering, and Mathematics (STEM) disciplines, artificial intelligence (AI) has demonstrated positive educational effects, including enhancements in academic performance, stimulation of critical thinking and problem-solving skills, and increased student interest and motivation. AI enables personalized and adaptive learning environments, providing supportive tools for autonomous learning. Technologically, AI has proven effective and precise in various applications, such as predicting student performance, automated assessment of open-ended responses, and improving predictive models. AI-based systems, including educational robots and virtual agents, have been developed to interact with students and offer personalized feedback. However, recent reviews Xu & Ouyang (2022) underline the invaluable potential of AI in higher education and STEM, emphasizing the need for continued research and advancements in this field.

In the context of online higher education, recent research Ouyang et al (2022) highlights the pivotal role of artificial intelligence in offering various beneficial functions, including

predicting learning progress, student performance, and satisfaction, resource recommendations, automated assessment, and enhancing the overall learning experience. These AI applications have gained widespread acceptance in educational settings and demonstrated positive outcomes, such as accurate AI-backed predictions, high-quality recommendations based on individual student characteristics, improved academic performance, and increased online engagement. The research suggests three key implications for future research: integrating educational theories into online learning with AI, adopting advanced AI technologies for real-time data analysis, and conducting empirical research to confirm the effects of AI applications in online higher education.

While previous studies Cosmes Aragón & Montoya Delgadillo (2021); Ghoniem & Ghoniem (2022) have explored mathematical modeling in engineering education and the need for technology-driven learning strategies in structural engineering, a gap remains in understanding the impact of AI on structural engineering education. Despite the proliferation of AI applications in Educational AI (AIED) seeking to enhance the learning process, previous research Chichekian & Benteux (2022) has indicated a lack of significant progress from a pedagogical and theoretical perspective in the AIED field. This suggests an unawareness of previous review findings that may have impeded its progress, emphasizing the necessity for a new review to address these limitations and contribute to advancing learning theories and the effective implementation of AI applications in the educational environment (Doblada & Caballes, 2021).

Therefore, promoting collaboration in researching and developing AI-based educational technologies is crucial for improving engagement in educational settings. This involves educators' involvement in decision-making and implementing AI applications in classrooms, focusing on creating learning experiences that consider student interaction with AI, including motivation and engagement. It is also essential to clearly define the role of teachers in the classroom and consider their perspectives in the development of AI-based educational technologies. Exploring the integration of interdisciplinary perspectives for AI use in educational environments becomes essential, emphasizing the importance of educators' involvement in assessing the pedagogical and ethical implications of implementing AI applications in classrooms. This contributes to the advancement of learning theories through a suitable and coherent conceptual framework.

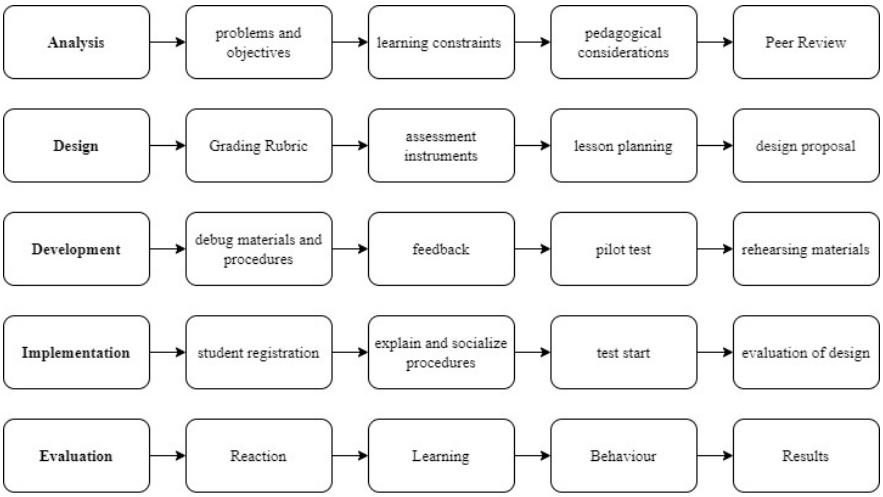
The overarching research question is then posed: What is the impact of using artificial intelligence (AI) in structural learning through programming in open-source software languages developed by early undergraduate civil engineering students, including student perception, academic performance, and factors contributing to AI success in the learning process?

Materials and methods

To conduct the study, the ADDIE methodology (Analysis, Design, Development, Implementation, and Evaluation) is employed, proven to be effective in the teaching and learning process (Almelhi, 2021). Within the evaluation phase, the Four Levels of Learning Evaluation by Donald Kirkpatrick (Kirkpatrick & Kirkpatrick, 2005) are utilized.

Results are derived from summative evaluation and a survey designed and administered to students. The components of each phase are outlined in the flowchart of the initial methodology in **¡Error! No se encuentra el origen de la referencia.**.

Figure 1. ADDIE Methodology Applied to the Case Study



A correlational research design and a questionnaire serve as data collection tools. Convenience sampling is applied, with the sample consisting of active students enrolled in the courses of rational mechanics and strength of materials in the second and third semesters, respectively, of the Civil Engineering program at the Universidad Nacional de Chimborazo.

Students developed programs for structural analysis and design using three open-source software: Python, Octave, and OpenSees, incorporating artificial intelligence applications to achieve this objective. The category of Artificial Intelligence Tutoring Systems (ITS) in the STEM education context is considered. ITS are AI-driven systems providing personalized instruction and feedback, fostering an adaptive and personalized learning approach. This includes various subcategories such as the delivery of instructional content, recommendation of personalized learning paths, and suggestion of learning resources. It's noteworthy that the group comprises students with varying levels of programming knowledge.

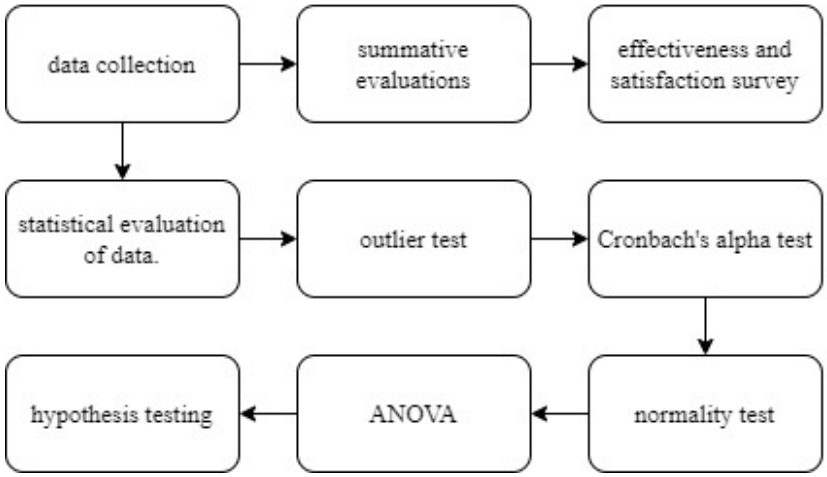
Before the information gathering phase using the survey, assurance of information confidentiality was provided to mitigate biases, particularly regarding expectations satisfaction towards the instructor. The survey was conducted before the evaluation and assignment of grades to explore relationships between satisfaction and effectiveness irrespective of the obtained grade.

To analyze the impact of the research, summative evaluations indicating goal attainment or non-attainment are employed. Additionally, to assess effectiveness and satisfaction, a survey was designed, developed, and administered. A quantitative approach is utilized for the questionnaire, comprising fifteen statements analyzing responses in terms of effectiveness and satisfaction. The Likert scale is employed with options (1)

Strongly Agree = 5, (2) Agree = 4, (3) Disagree = 3, (4) Disagree = 2, and (5) Strongly Disagree, adapted to each question.

The hypothesis verification is carried out through variable correlation. The obtained data are first analyzed using various statistical tests: outlier test, Cronbach's reliability test, normality test, conventionally true value, and correlation tests, following a methodology similar to that proposed by Nurmayanti & Suryadi (2023).

Figure 2. Statistical Data Analysis Methodology



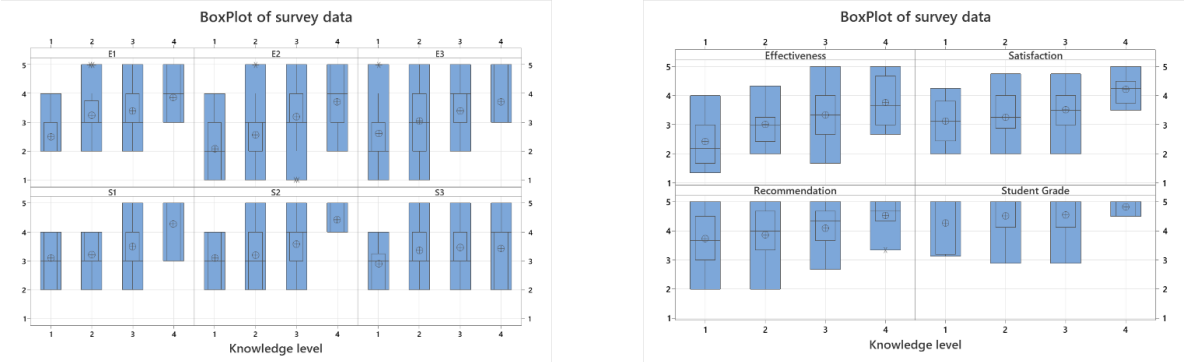
Results

To verify the validity and reliability of the results, the statistical analysis specified in the methodology was conducted. The student group corresponds to N = 90 before the removal of outliers, and the analysis is performed with a 5% significance level.

Outlier Test Using Boxplots

The first step involved analyzing the data to identify outliers. 3 displays the results after this procedure for the variables of Effectiveness, Satisfaction, Recommendation, and student grade.

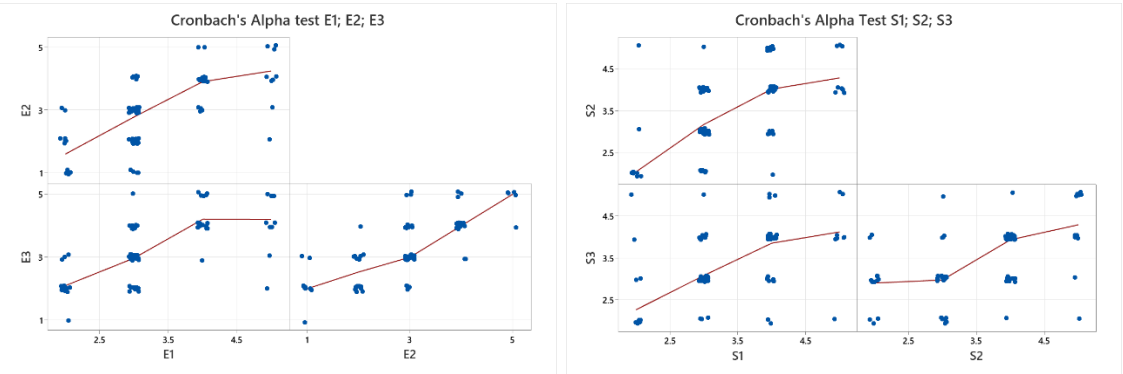
Figure 3. Boxplot depicting the knowledge level against the studied variables



Cronbach's Alpha Reliability Test

This test assesses the internal consistency or reliability of a set of data or questions on a measurement scale. The resulting value, known as "Cronbach's alpha," indicates how consistent and reliable the dataset is in terms of measurement. A higher Cronbach's alpha value is generally interpreted as higher reliability in measurements. The questionnaire is considered moderately reliable if the Cronbach's alpha value > 0.6. The test is not dependent on whether the data follows a normal or non-normal distribution, making it applicable to all data (Taber, 2018).

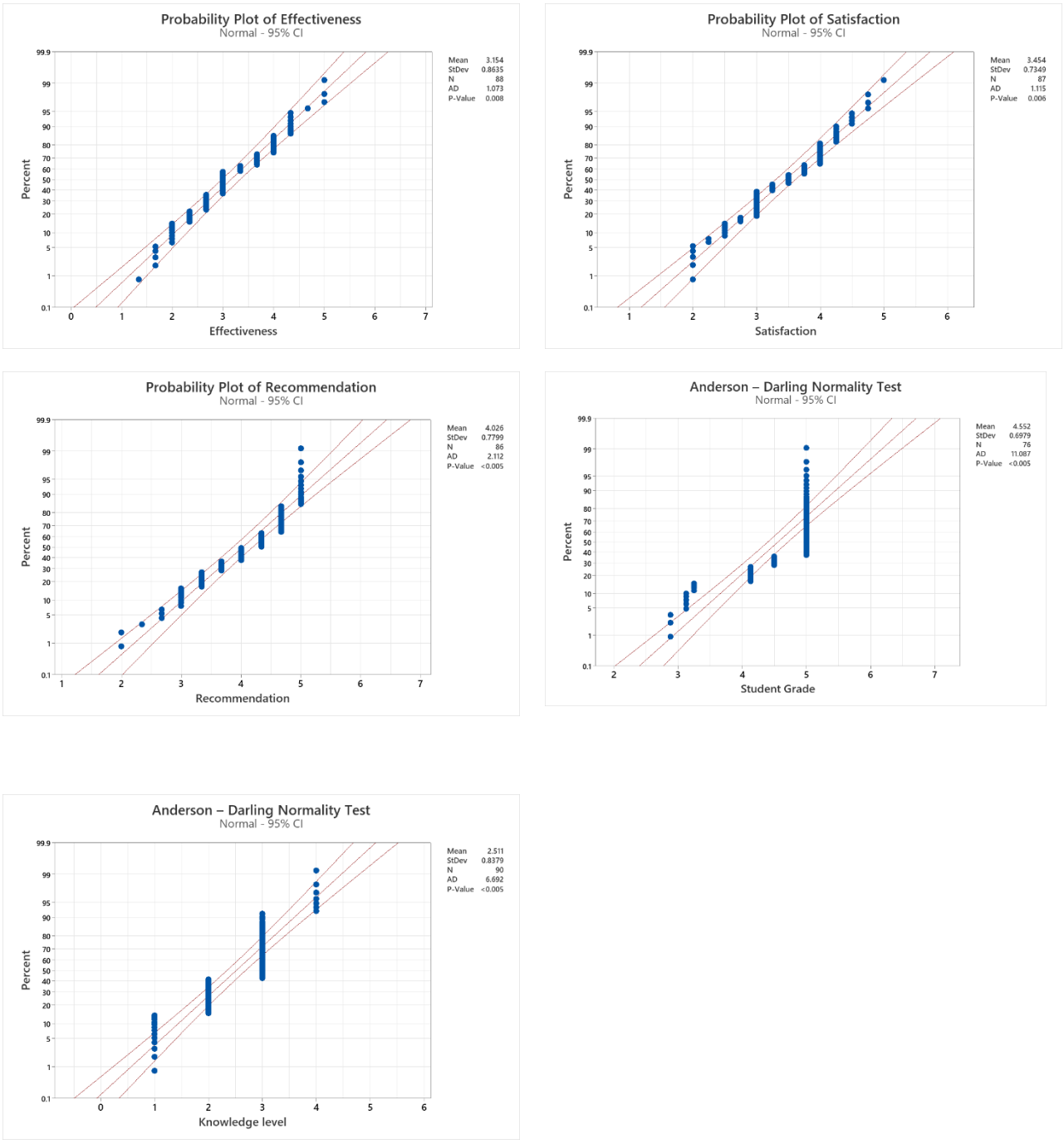
Figure 4. Results of Cronbach's Alpha test



Normality Test

After removing outliers and conducting the Cronbach's test, the normality curves are examined using the Anderson–Darling test. Results are shown in Figure 5.

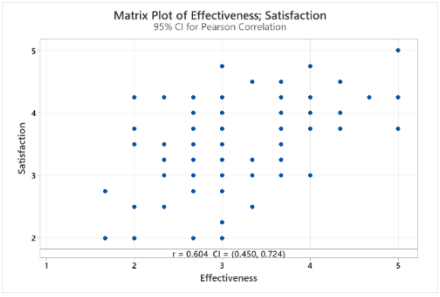
Figure 5. Anderson–Darling Normality Test

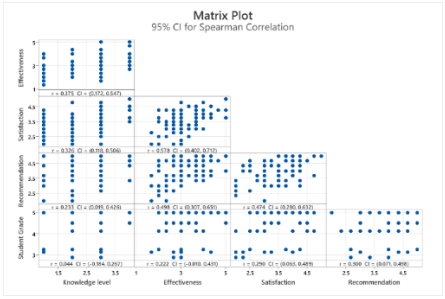


Correlation Test

Pearson correlation is performed for variables with a normal distribution, i.e., Satisfaction and Effectiveness. For the remaining data, Spearman correlation is applied (Shestakov et al., 2022).

Figure 6: Pearson correlation between Effectiveness and Satisfaction and Spearman correlation between all variables

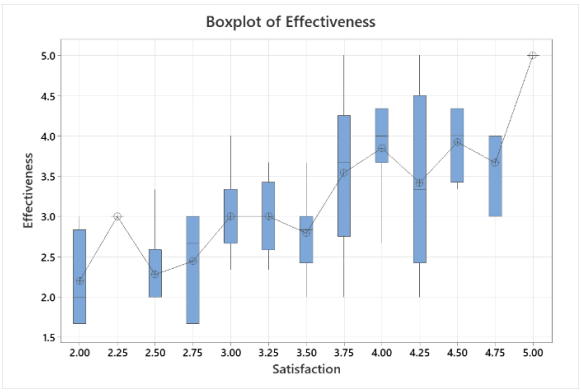


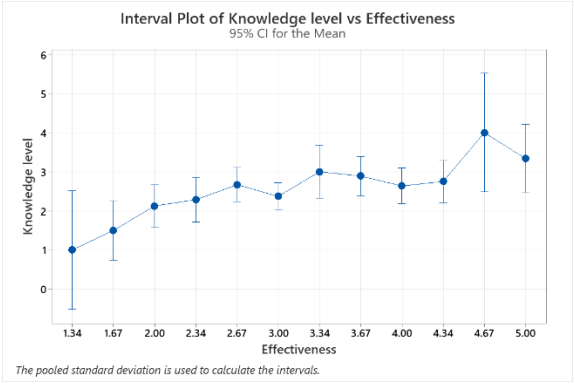


ANOVA Test

ANOVA assumes that populations from which samples are drawn should follow a normal distribution. However, ANOVA is robust to moderate deviations from this assumption, especially when the sample size is large. (Zhao et al., 2021) The ANOVA test is conducted between Effectiveness and Satisfaction, and between variables, as depicted in Figures 7 and 8.

Figure 7. ANOVA test between Effectiveness and Satisfaction





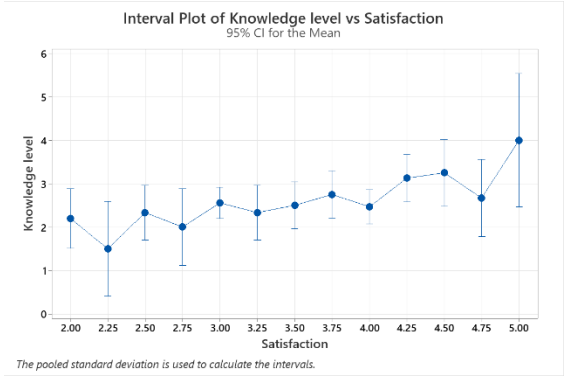
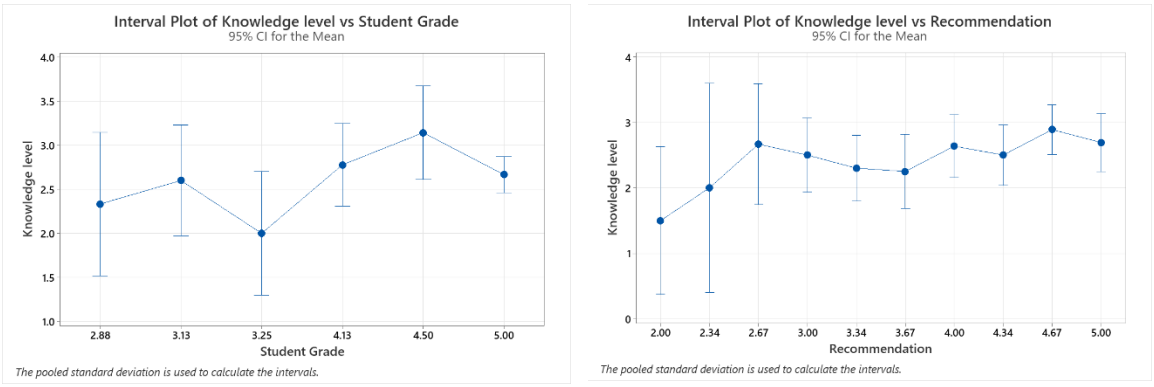


Figure 8. ANOVA test between variables

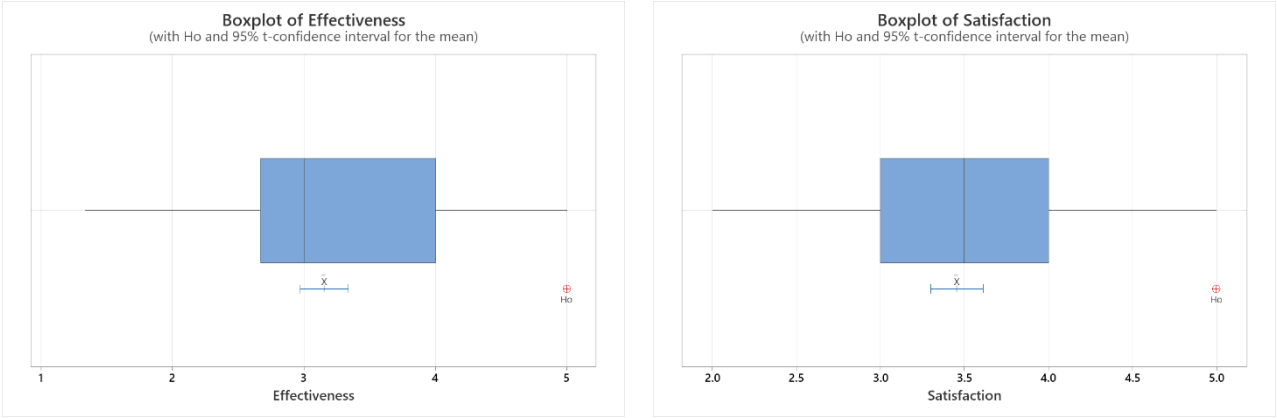


Conventional True Value

Considering that Effectiveness and Satisfaction have a normal distribution, a one-sample t-test is conducted. The assumption is that the exercise is perceived as effective and with a high degree of satisfaction. The graph indicates that the effectiveness is perceived as moderate, and satisfaction ranges from moderate to high, as shown in Figure 9.

The Recommendation and Grade do not follow a normal distribution, leading to the application of the non-parametric Wilcoxon test (Fay & Proschan, 2010). The median, with a 95% confidence level, is 4 for Recommendation and 4.75 for Grade.

Figure 9. Hypothesis Test



Chi-Square Test for Association

Considering that Effectiveness and Satisfaction have a normal distribution, a chi-square test for association is performed. Table 1 presents the relationship between Effectiveness and the variables (Doblada & Caballes, 2021).

Table 1. *Relationship between the Efectiveness and variables.*

Effectiveness	Chi-square value	df	p-value	Decision on Ho	Remarks
Knowledge	2.536	6	0.864	Failed to reject	Not significant
Satisfaction	2.873	2	0.238	Failed to reject	Not significant
Student Grade	0.078	3	-	Failed to reject	Not significant

(Note: df = degrees of freedom)

Starting with the main finding, after the analysis, it was deemed necessary to exclude outlier cases, including students who couldn't complete the activity due to reasons beyond the study's scope. Exploratory graphs were employed to identify these and other outliers to ensure they did not distort the results.

Upon obtaining data post-outlier removal, the Cronbach's alpha test was conducted. The values obtained were 0.8691 for effectiveness and 0.7667 for satisfaction, establishing the test's reliability for these parameters.

Normality tests were also performed on the variables. It was observed that effectiveness and satisfaction follow a normal distribution, while student grades, recommendations, and student grades do not. The asymmetry in the variable distributions suggests that linear patterns might not be followed, prompting the consideration of non-parametric statistical methods. Hence, in addition to the Pearson correlation test, the Spearman correlation test is proposed.

In the correlation tests, the strongest correlation is found between effectiveness and satisfaction. Relationships between the other variables range from moderate to low, indicating a lack of strong associations.

The ANOVA test aids in better understanding relationships between variables. The students' programming knowledge was related to effectiveness, satisfaction, student grades, and their recommendation of this learning methodology. Linear ascending relationships were noted, suggesting a positive linear relationship between variables. In other words, as students' knowledge increases, their perception of effectiveness, satisfaction, recommendation, and student grades also increases. This implies that teaching positively influences the use of artificial intelligence.

Hypothesis tests reveal that the perceived effectiveness is above the mean value, suggesting that students generally believe the objectives were achieved within the required timeframe. Satisfaction is very close to the mean. Regarding recommendation,

results indicate that students generally recommend the use of the methodology, while student grades, excluding outliers, show that students achieved the exercise objectives.

The association between responses in a chi-square test on students' knowledge and exercise effectiveness (p-value of 0.864) suggests no significant evidence to reject the null hypothesis that there is no association between these two variables. A similar situation arises with student satisfaction and effectiveness (p-value of 0.238) and the relationship between student grades and effectiveness (Pearson Chi-Square of 0.078).

During the study, it became apparent that the use of AI does not accurately reflect the true learning state of students. Perhaps a shift towards an intelligent tutoring system could yield better results (Francisco & Silva, 2022). It's also noteworthy that students who have not yet received formal education in programming consider themselves to have a higher level of knowledge than those who have completed that level. This reflects a statistical phenomenon rather than a reflection of human nature (the Dunning-Kruger effect) (Magnus & Peresetsky, 2022).

Conclusions

Despite the statistical data not revealing a strong relationship between variables, a notable correlation is observed between students' effectiveness and satisfaction. This suggests that as results are achieved within the expected timeframe, students feel their expectations are fulfilled. Furthermore, it appears that students with less programming knowledge show lower levels of satisfaction and effectiveness, while those with more programming knowledge exhibit higher levels of satisfaction and effectiveness.

Regarding the use of open-source software packages, it is evident that individuals with limited programming knowledge encounter difficulties with all packages. In contrast, those with greater knowledge find Python easier, followed by Octave and, finally, OpenSees. There are outliers in the moderately knowledgeable programming group—some find Python very easy, while others find it challenging. The relationship between effectiveness and knowledge seems proportional. The perception of the utility of open-source software programs is similar for all three options, with those who believe they have more knowledge finding them more useful than those who think they lack programming knowledge.

The initial level of knowledge doesn't impact as much as the motivation of the students. Qualitative analysis of questions suggests that while artificial intelligences are helpful for problem-solving, they function to the extent that tools can be managed and are accessible. Explanations by professionals seem to yield better results, emphasizing that, for now, artificial intelligence cannot replace the role of teachers but is necessary for the proper and complementary use of these tools.

The pursuit of knowledge is crucial as it allows exploration of fields that benefit effective learning. As Alexander Pope stated, "A little learning is a dangerous thing."

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