

An interactive PYTHON-STREAMLIT application to strengthen vector learning for engineering students

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Abstract—This paper presents an educational innovation based on an interactive web application developed in PYTHON and deployed online using STREAMLIT, aimed at reinforcing the learning of vector algebra in first-year engineering students. The activity focuses on practicing basic algebraic operations with vectors in two and three dimensions, including conceptual knowledge. The application is designed according to an active and adaptive learning approach, in which students progress through successive levels. If a response is incorrect, alternative versions of the same-level problem are generated, allowing students to retry without penalty. To evaluate the impact of the activity, a pre-test and a post-test were administered, including procedural problems, open questions and Likert-scale items. The intervention was implemented in seven first-year engineering groups, summing a total of 155 students. The comparative analysis of pre- and post-test results shows that the average score increased by 7.15 points and that the dispersion of the data decreased, indicating a more homogeneous level of understanding among students after the activity. Additionally, the students perception highlight their preference for the use of interactive applications, emphasizing that such tools make the learning process more engaging and interesting.

Keywords—Vector algebra; Interactive learning applications; Science education; Active learning.

I. INTRODUCTION

Vector algebra constitutes a core component of introductory courses in mathematics, physics, and engineering, as it provides essential tools for modeling physical phenomena and understanding engineering systems, for instance, kinematics, dynamics, torque and electromagnetic phenomena [1], [2]. Mastery of vector operations requires the coordinated use of algebraic manipulation, geometric interpretation, and spatial reasoning. However, empirical research consistently reports persistent conceptual and procedural difficulties among first-year students, particularly in vector decomposition, coordinate transformations, and transitions between graphical and symbolic representations [3], [4].

These learning difficulties are frequently attributed to fragmented representational understanding and limited opportunities for dynamic visualization and immediate feedback. From the perspective of multiple representation theory and cognitive load frameworks, instructional environments that integrate symbolic and graphical representations in an interactive manner may reduce extraneous cognitive load and enhance conceptual coherence.

In recent years, digital technologies have assumed an increasingly prominent role in higher education, fostering the development of interactive learning environments aimed at enhancing student engagement and learner autonomy [3], [5]–[7]. Despite the growing availability of digital tools for vector visualization, existing studies reveal two persistent limitations: (1) a reliance on predominantly descriptive or perception-based evaluations, and (2) a scarcity of empirical evidence derived from controlled or quasi-experimental research designs capable of demonstrating measurable learning gains.

As a result, there remains a clear need for rigorously evaluated instructional interventions that explicitly address the conceptual integration of algebraic and geometric vector representations while providing quantitative evidence of their educational effectiveness.

Within this framework, educational innovation can be understood as the systematic integration of novel tools, methodologies, or instructional strategies designed to produce demonstrable improvements in learning outcomes [8]–[10].

This study addresses this gap by designing and implementing an interactive web-based learning activity developed in PYTHON using STREAMLIT¹. The intervention integrates dynamic vector visualization, real-time computational feedback, and guided problem-solving tasks aligned with introductory engineering curricula.

The objectives of this study are to examine whether participation in the interactive activity leads to statistically significant improvements in students' conceptual and procedural understanding of vector operations, to analyze changes in their ability to translate between algebraic and graphical vector representations, and to evaluate the magnitude of the intervention's effect relative to traditional instructional approaches.

By combining a theoretically grounded instructional design with quantitative evaluation, this work aims to contribute empirical evidence regarding the effectiveness of interactive digital tools in foundational engineering mathematics education.

II. DESCRIPTION OF THE INTERACTIVE ACTIVITY

The interactive activity consists of a web-based application designed to support students' practice and consolidation of

¹<https://streamlit.io/>

fundamental vector algebra operations. The application targets key conceptual and procedural aspects commonly addressed in introductory mathematics, physics, and engineering courses, including:

- The conceptual definition of vectors
- The representation of vectors and their components in two- and three-dimensional Cartesian coordinate systems
- Vector addition and subtraction using the component method
- Scalar multiplication of vectors.

The activity comprises eight core vector exercises, each of which can be repeatedly instantiated through automatically generated alternative versions with equivalent levels of difficulty. This design ensures variability in numerical values and configurations while preserving the underlying conceptual demands of each task, thereby reducing rote memorization and promoting conceptual understanding.

The application follows an adaptive progression logic. For each exercise, a problem is initially presented to the student. When a correct response is submitted, the system provides immediate confirmation feedback, after which the student may proceed to the next exercise or continue practicing additional variants of the current task. If an incorrect response is submitted, the system generates a new version of the same-level problem, or alternatively allows the student to switch to a different exercise and return later.

Students are permitted an unlimited number of attempts, a feature intended to encourage experimentation, reflection on errors, and iterative conceptual refinement. As evidence of task completion, students are required to capture a screenshot of the confirmation message displayed after a correct response and submit it through the institutional learning management system (Canvas).

Fig. 1 shows the cover page of the app and an example of a tab containing an exercise. Through these tabs, students practice the eight vector topics included in the activity.

III. METHODOLOGY

The interactive activity was implemented across seven first-year student groups enrolled in different engineering degree programs. All groups participated under identical instructional conditions and used the same version of the web-based application, ensuring consistency in the intervention.

To assess the educational impact of the intervention, a pre-test and a post-test were administered in Canvas. Both instruments included a combination of procedural problems, open-ended questions designed to probe students' conceptual understanding of vector algebra and Likert-scale items aimed at capturing students' perceptions of their learning and the perceived usefulness of the activity.

The pre-test and post-test were constructed using problems of equivalent difficulty and aligned content coverage in order to enable a valid comparison of student performance before and after the intervention. This design supports the analysis of learning gains attributable to participation in the interactive activity.

The top image shows the app's cover page. It has a dark theme with a navigation bar at the top containing links: Instruction, Components 2D, Magnitude and angle, Sum 2D, Subtraction 2D, Sum and subtraction 2D, and Components 3D. The main heading is 'Instruction'. Below it, a message says 'Vectors are cool' with a sunglasses emoji. The instructions state: 'This Activity is to practice algebraic operations with vectors. The activity is centered in components of vectors, sum and subtraction of vectors in 2D and 3D. A problem will be presented, if your answer is correct, continue to the next problem or practice another version. If your answer is incorrect, try with another version or jump to a new problem and then come back.' There is a text input field for the user's name.

The bottom image shows a specific exercise tab titled 'Sum and subtraction 2D'. The sub-heading is 'Sum and subtraction of three vectors in 2D'. The instruction says: 'Calculate the result of the operation $(a - b + c)$ of the given vectors. Enter the result and press Submit.' Below this is a graph titled 'Sum and subtraction of three vectors in 2D'. The graph shows a 2D Cartesian coordinate system with x and y axes ranging from -5.0 to 5.0. Three vectors are plotted: vector 'a' (green) from (0,0) to (3, -3), vector 'b' (blue) from (0,0) to (-3, -4), and vector 'c' (orange) from (0,0) to (-2, 4). Below the graph, the vectors are defined: 'Vector a = [4 -3]', 'Vector b = [-5 -4]', and 'Vector c = [-3 4]'. There are input fields for 'Enter the x component of $(a - b + c)$ ' and 'Enter the y component of $(a - b + c)$ ', both currently showing '0'. There are 'Submit' and 'Try Again with new vectors (2D)' buttons.

Fig. 1. Examples of the vector app. Top: the app's cover page. Bottom: a tab displaying a sample type of exercise.

Normality of the paired score differences was assessed using the Shapiro–Wilk test prior to conducting a paired-samples t-test.

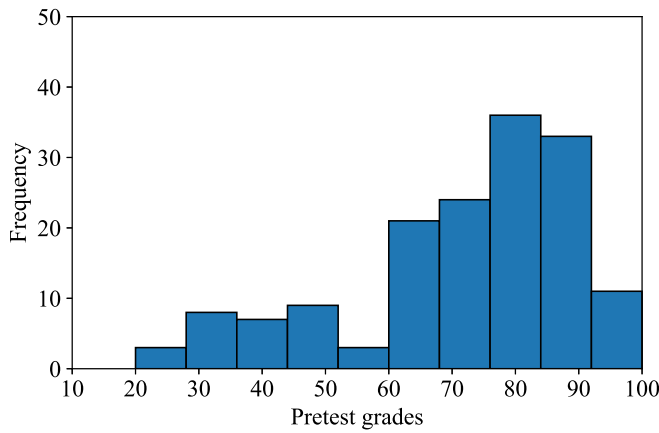


Fig. 2. Distribution of pre-test scores assessing students' understanding of vector algebra prior to the intervention ($n = 155$, mean = 71.69, SD = 19.18).

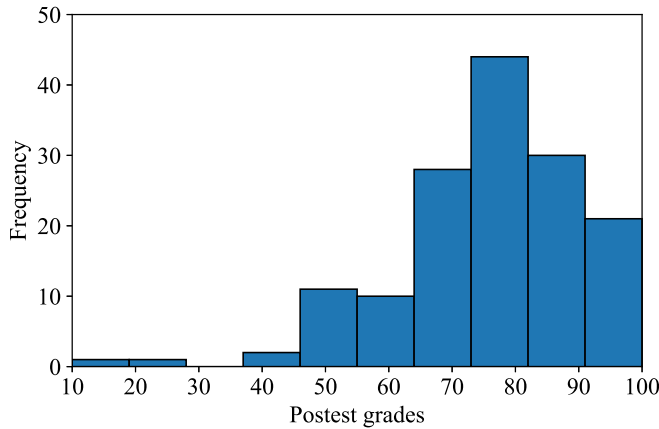


Fig. 3. Distribution of post-test scores assessing students' understanding of vector algebra after the intervention ($n = 148$, mean = 77.97, SD = 16.27).

IV. RESULTS

The histogram of Fig. 2, corresponding to students' grades before the use of the application includes a total of 155 observations and shows an average score of 71.69, with a median of 76.67. The discrepancy between the mean and the median suggests a slightly skewed distribution, with a considerable spread of values. This observation is reinforced by a relatively high standard deviation of 19.18, indicating substantial variability in students' performance prior to the intervention. Overall, the pre-test results reflect a heterogeneous level of understanding of vector-related concepts among students before the intervention.

In contrast, Figure 3 presents the distribution of post-test scores obtained after the implementation of the interactive activity. This histogram shows that mean score increased to 77.97 and the median to 80.00, indicating a shift in central tendency toward higher values. At the same time, the standard deviation decreased to 16.27, corresponding to a reduction of 2.91 points relative to the pre-test. This reduction in dispersion suggests

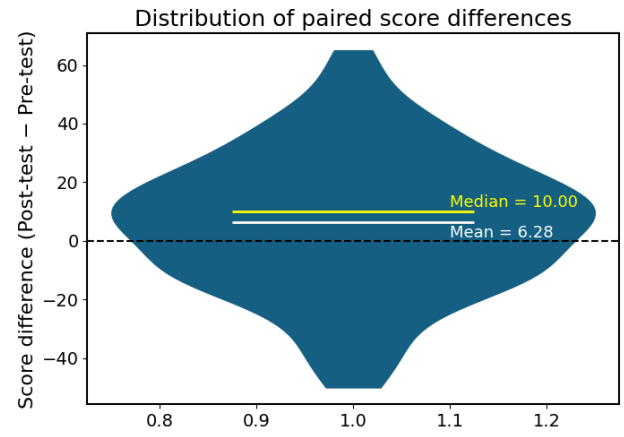


Fig. 4. Violin plot of paired score differences (post-test minus pre-test) for students who completed both assessments. The distribution is centered above zero, indicating a positive learning gain. The white line denotes the mean difference (6.28 points), while the yellow line represents the median difference. The dashed horizontal line marks zero gain.

that students' performances became more concentrated around higher values, reflecting not only an overall improvement in grades but also a greater consistency in learning outcomes following the use of the application. It is worth noting that histogram of Fig. 3 is composed of a total of 148 entries, indicating that seven student completed the pre-test but did not responded the post-test. Given the minimal difference in sample size, this missing observation is not expected to substantially affect the overall statistical trends reported here.

A. Statistical evidence of learning gain

While the descriptive comparison of pre-test and post-test score distributions suggests an overall improvement in student performance, a paired-samples statistical analysis was conducted to formally determine whether this change represents a statistically significant learning gain among students who completed both assessments. To maintain a consistent sample size across analyses, the seven students who completed the pre-test but did not respond to the post-test were retained by imputing their missing post-test scores using the sample mean. Given the small proportion of missing data, this imputation is not expected to substantially affect the overall statistical trends.

Prior to hypothesis testing, the distribution of paired score differences (post-test minus pre-test) was examined using the Shapiro–Wilk normality test. The results indicated no significant deviation from normality ($W = 0.986$, $p = 0.121$), thereby supporting the use of a parametric paired t -test to evaluate mean differences.

The paired t -test (one-tailed, greater) revealed that post-test scores were significantly higher than pre-test scores, $t(154) = 3.295$, $p = 0.0006$. The mean score increased by 6.28 points, with a 95% confidence interval ranging from 2.52 to 10.05 points. Accordingly, the null hypothesis ($H_0 : \mu_d \leq 0$) was rejected in favor of the alternative hypothesis ($H_1 : \mu_d > 0$), indicating that participation in the interactive activity was associated with a statistically significant learning gain.

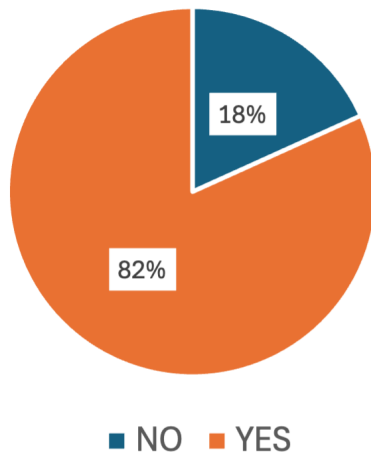


Fig. 5. Self-reported use of the vector application prior to completing the post-test ($n = 148$ respondents). Percentages indicate the proportion of students who reported using or not using the application.

Cohen's d is a measure of effect size that expresses the difference between two means in standard deviation units. Cohen's original conventions [12] classify values of 0.2 as small, 0.5 as medium, and 0.8 as large. To quantify the magnitude of the observed learning gain, we computed Cohen's d for paired samples. The resulting effect size ($d = 0.265$) falls slightly above the conventional "small" threshold. Although modest by laboratory standards, this effect size is meaningful in the context of short-duration educational interventions designed to complement, rather than replace, traditional instruction.

This effect size aligns well with typical findings in educational technology research. A recent meta-analysis of 72 studies reported a mean effect size of $d = 0.202$ for technology-based interventions on student achievement [13], and a second-order meta-analysis covering four decades of research found an average effect of $d = 0.33$ for technology applications in K-12 and higher education [14]. Given that field-based educational interventions often yield effects substantially smaller than those observed in other disciplines, the observed gain of $d = 0.265$ represents a practically meaningful contribution to student learning [15].

Furthermore, the percentage learning gain relative to the pre-test mean was 8.77%, reinforcing the practical relevance of the observed improvement.

Figure 4 presents a violin plot of the paired score differences (post-test minus pre-test) for students who completed both assessments. The distribution is clearly shifted toward positive values, with both the mean (6.28 points) and the median (10 points) located above zero, providing visual confirmation of the statistically significant learning gain identified by the paired t -test. The relatively symmetric shape of the distribution is consistent with approximate normality, supporting the assumptions underlying the parametric analysis. Together with the numerical results, this visualization reinforces the conclusion that the observed improvement reflects genuine

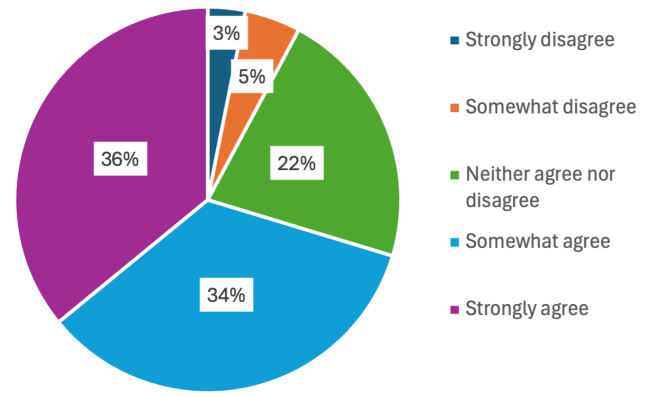


Fig. 6. Student responses to the statement: "The 'Vectors are cool' application helped me better understand the topic of vectors". Percentages correspond to the distribution of Likert-scale responses (Strongly disagree to Strongly agree).

learning rather than random variation.

B. Use of application

Fig. 5 shows the percentage of students who reported using the application presented in this work. A clear majority (82%, corresponding to 121 students) indicated that they used the app, while 18% (27 students) chose not to use it, as participation in the activity was optional. The reasons for non-use were not investigated. A separate analysis comparing students who used the application with those who did not is presented in the Analysis section. The results discussed in this section are based on the complete observations, including all participants.

C. Student perceptions of the application

The applied Likert scale identifies the students' perception about the app. The questions were the following: The "Vectors are cool" application helped me better understand the topic of vectors. The use of the "Vectors are cool" application made the learning process more interesting. Based on what you learned after using the "Vectors are cool" application, do you think vectors are clearer to you now? The options on the Likert scale were: Strongly disagree, Somewhat disagree, Neither agree nor disagree, Somewhat agree, Strongly agree.

Fig. 6 presents the results for the first Likert-question. A total of 70% of the students reported agreement at some level (somewhat or strongly) that the application helped them better understand vector concepts, with the proportion of strongly agree responses exceeding that of somewhat agree. In contrast, 22% of the respondents were undecided, while only a small minority (8%) disagreed to some extent. These results indicate that most students perceived the app as beneficial and that it contributed positively to their understanding of vector concepts.

Comparable outcome statistics were obtained for students' perceptions of the learning process as interesting when using the app (see Fig. 7). A total of 72% of the respondents agreed, at some level, that the app made learning about vectors more interesting, while 22% neither agreed nor disagreed, and

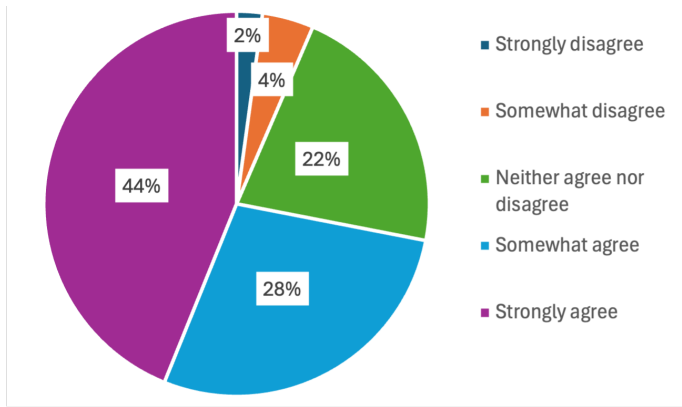


Fig. 7. Distribution of student responses to the statement: “The use of the ‘Vectors are cool’ application made the learning process more interesting,” measured on a five-point Likert scale.

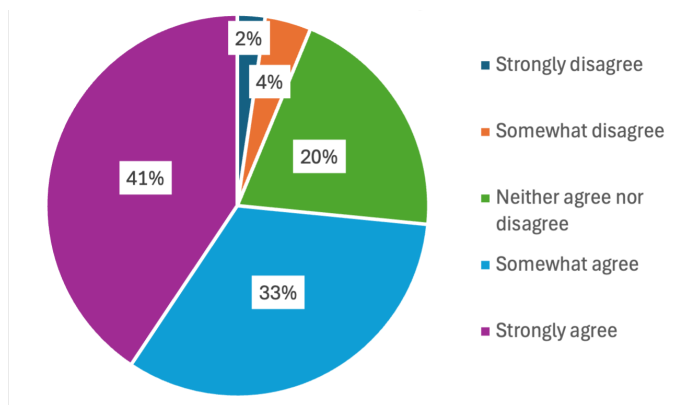


Fig. 8. Distribution of student responses to the statement: “Based on what you learned after using the ‘Vectors are cool’ application, do you think vectors are clearer to you now?” measured on a five-point Likert scale.

only 6% disagreed. These results suggest that this type of application is perceived as particularly effective in increasing students’ interest, even more so than in improving conceptual clarity (compare Fig. 8 and 7). Students appear to favor innovation in the learning process, even when the topic is not yet fully clear, indicating that current learners are especially receptive to new methodologies that enhance engagement and make learning more interesting [7], [11].

Regarding the final Likert-scale question on the clarity of vector concepts after using the activity, 74% of the students agreed to some extent that vectors were clearer, while only 6% disagreed and 20% selected a neutral response. These results indicate a clear consensus that the activity contributed to improved conceptual clarity of the topic.

D. Qualitative analysis of student difficulties

The analysis of students’ responses to the open-ended question “In your own words, what do you find most difficult about the topic of vectors?” reveals several recurring difficulties. The most frequently reported concerns vectors in three dimensions, particularly the visualization of vectors in 3D space, and

the incorporation of the z -axis into previously learned two-dimensional representations.

A large number of students also reported confusion regarding the use of trigonometric functions (sine, cosine, and tangent), especially when deciding which function to apply to obtain vector components and when working with inverse trigonometric functions.

Additionally, but in less degree, responses highlight problems with memorizing formulas, selecting the appropriate formula for a given situation, and applying them correctly in procedural problems.

Despite these reported challenges, several students explicitly stated that practice with the application helped them improve their understanding. Overall, the qualitative responses suggest that spatial visualization, conceptual integration of representations, and the coordinated use of trigonometry and sign conventions constitute the main obstacles in learning introductory vector algebra.

V. ANALYSIS

It is noteworthy that the histograms reveal that, although the average score increased slightly after the use of the application – by 6.28 points – the dispersion of the data, as measured by the standard deviation, shows a clear reduction. This trend is also reflected in the closer proximity of the median and average values in the post-test (a difference of 2.03 points) compared with the pre-test (a difference of 4.98 points). Together, these indicators suggest that the post-test score distribution is narrower than that of the pre-test.

The decrease in variability indicates that students’ performances became more clustered around the mean, pointing to greater consistency across the groups. From an educational perspective, this pattern suggests that the application may have contributed not only to a modest overall improvement in performance but also to a more homogeneous level of understanding of vector concepts among students.

Across the Likert-scale questions, a high level of agreement was observed, with approximately 70% (70-74 percent) of respondents selecting either strongly agree or somewhat agree. Around 20% (20-22 percent) of the students neither agreed nor disagreed, while only about 6% (6-8 percent) disagreed across all Likert items. These results indicate a consistently positive perception of the activity and the application among the participants.

However, the question showing the strongest dominance of strongly agree responses was the one related to the activity making the learning process more interesting (44% over 41 and 36 percent). This pattern suggests that students particularly valued the engaging and interactive aspects of the activity, highlighting the relevance of instructional approaches that emphasize engagement alongside conceptual learning.

However, according to Fig. 5, 18% of the students did not use the vectors application. After excluding those students from the dataset, the histogram density decreases, but more importantly, the average score increases slightly from 77.97 to 78.84 (see Fig. 9), while the median remains unchanged.

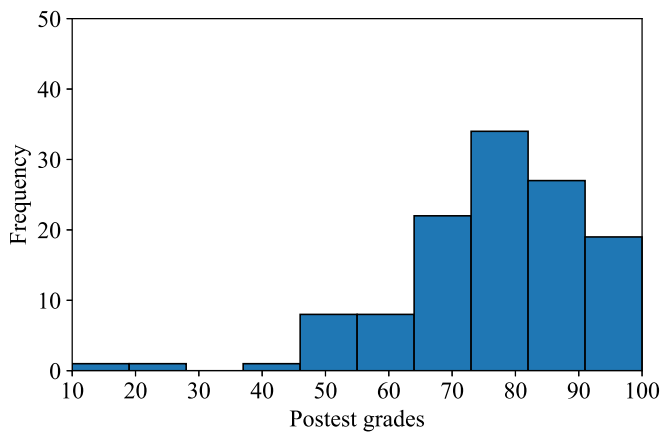


Fig. 9. Distribution of post-test scores for students who reported using the vector application prior to the assessment ($n = 121$, mean = 78.84, SD = 16.54).

The new standard deviation (16.54) increases only marginally by 0.27 compared with the posttest standard deviation calculated using the full dataset. Therefore, the mean performance improves and the overall classroom homogeneity remains essentially the same.

VI. LIMITATIONS AND FUTURE WORK

A limitation of this study is the absence of a control group that did not participate in the activity, which restricts the ability to make direct comparisons with traditional learning approaches. Additionally, although the activity was implemented during the same initial period of the semester, class schedules were not simultaneous. Given the constant communication among students, it is possible that those who participated earlier shared information with peers scheduled later, potentially influencing the results.

As future work, it would be important to identify which types of vector problems present the greatest difficulty in order to target those topics more effectively. Further refinement of the Python-based tool based on student feedback is also recommended. It is also necessary to measure the effect of students who completed the pre-test but not the post-test on the results. Finally, increasing the sample size would enable a more robust statistical analysis.

VII. CONCLUSION

This study demonstrates that an interactive web application developed in PYTHON and deployed using STREAMLIT can serve as an effective tool for reinforcing vector algebra learning in first-year engineering students [4]. The combination of adaptive problem generation, immediate feedback, and unlimited attempts supports autonomous learning and helps students consolidate essential vector concepts and procedures.

The results provided by the pre- and pos- tests suggest that such digital tools can complement traditional instruction and contribute to improved engagement and understanding in introductory STEM courses [7], [11].

The statistical results show an increase in the average grades from 71.69 to 78.84 and, more importantly, a clear reduction of in the standard deviation (19.18 to 16.54) meaning a reduction in the performance gaps within the groups, leading to a more homogeneous class level. This leveling effect can help standardize students' knowledge and support a smoother progression toward subsequent topics involving vectors. Contemporary students tend to prefer innovative and playful learning tools during the instructional process [16]. Finally, from the students' perspective, spatial visualization emerges as the primary difficulty, suggesting that instructional efforts should be directed toward strengthening abstract and spatial reasoning skills.

Future work will focus on expanding the application to include additional vector-related topics and on conducting studies with larger samples to further investigate its educational effectiveness.

ACKNOWLEDGMENT

We thank the teachers who allowed us to conduct the activity in their classes and shared their data with us. We would like to thank the anonymous reviewers for their valuable comments and suggestions, which significantly improved both the quality of the manuscript and the scientific content of the document.

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