Advancing Education by Integrating Additive Learning Tools into Teaching Practices

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***Abstract*—This study investigates the impact of additive learning tools on the educational outcomes of first-year engineering students. Employing a structured experimental framework, the research divided participants into three groups: a control group and two experimental groups, one with teacher facilitation and the other without. Utilizing technologies such as SolidWorks, LabVIEW, Unity, and Unreal Engine, the study measured variables including academic performance, intrinsic motivation, collaborative skills, and student satisfaction. Results from Kruskal-Wallis tests and ANOVA confirmed that students using additive learning tools under teacher guidance (Experimental Group 1) exhibited significantly enhanced academic performance and motivation compared to the control group and the group using technologies independently. However, no significant differences were found in collaborative skills across all groups, suggesting the need for tailored pedagogical strategies to leverage technological benefits fully. Furthermore, high satisfaction rates among students in the experimental groups underscore the positive reception and effectiveness of these learning tools. This study contributes to the discourse on integrating innovative educational tools in engineering curricula, advocating for enhanced teacher involvement to maximize learning outcomes, and highlights areas for further research in technology-enhanced education.**

***Keywords*—additive learning tools, engineering education, academic performance, student motivation, collaborative skills, educational technology, pedagogical strategies**

I. Introduction

In the dynamic field of engineering education, Project-Based Learning (PBL) has become a key method for enhancing student competencies and readiness for professional life. This approach emphasizes real-world problems and collaborative learning, and it is widely adopted across various disciplines to develop critical thinking, problem-solving, and teamwork skills [1, 2]. As engineering challenges grow increasingly complex and interdisciplinary, there is a pressing need for innovative educational strategies that go beyond traditional learning paradigms [3].

The concept of PBL, initially developed for medical education, has been successfully adapted to engineering, significantly transforming curricular structures and teaching methods [4]. Unlike traditional lecture-based education, PBL engages students in project-driven scenarios that mimic real engineering tasks, effectively bridging the gap between theory and practice [5, 6]. This immersive approach not only improves technical skills but also deepens understanding, as students learn to apply concepts in diverse contexts [7].

Integrating additive tools like 3D printing and CAD software into PBL settings enhances engineering education by allowing students to prototype and refine designs rapidly. This hands-on approach provides immediate feedback and improves spatial reasoning and design skills essential in engineering [6, 7].

Moreover, integrating additive learning tools within a PBL framework matches current industry shifts towards rapid prototyping and agile development. Industries increasingly use these technologies to reduce product development time and boost innovation [8]. By incorporating these tools in educational settings, institutions equip students with relevant skills for modern engineering roles, enhancing their job market competitiveness [9].

However, while the benefits of using PBL and additive learning tools in engineering education are clear, implementing these methods presents significant challenges. Issues such as curriculum integration, faculty training, and the high costs of advanced technology pose barriers [10]. Despite these obstacles, the potential benefits to learning outcomes warrant thorough evaluation of these educational approaches within the engineering field.

The academic literature strongly supports the effectiveness of PBL in enhancing student learning outcomes in engineering education [11]. Studies show that students in PBL environments retain more information, solve problems better, and are more satisfied than those in traditional settings [12]. Similarly, research on additive learning tools shows substantial improvements in student engagement, creativity, and understanding of complex concepts [13].

This paper explores the synergistic impact of combining PBL with additive learning tools in engineering education. This study reviews literature and analyzes data from educational initiatives, contributing to discussions on integrating innovative technologies in engineering curricula. It aims to show how these tools enhance technical skills and foster a culture of innovation and continuous learning among engineering students.

The integration of project-based learning and additive tools in engineering education enhances student competencies and readiness for modern challenges. As the field evolves, continued research and investment are essential. This paper addresses these issues, offering insights and recommendations for educators, policymakers, and industry leaders to cultivate a dynamic and adaptable engineering workforce.

II. Literature Review

The adoption of additive learning tools in engineering education has emerged as a pivotal factor in reshaping pedagogical strategies and student learning outcomes. This literature review systematically explores the multifaceted impact of these technologies, examining their integration into

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curricula, the enhancements they bring to educational environments, and the challenges they pose. Each subsection delves into specific areas: the direct effects of these tools on student capabilities, the evolving landscape of technological advancements and their integration into teaching practices, the logistical and instructional challenges of implementing such tools, and a comparative analysis that evaluates traditional teaching methods against those augmented by additive tools. Through this review, we aim to provide a comprehensive overview of the current state of research in this field, identifying trends, gaps, and future directions for the use of additive learning tools in project-based learning (PBL) environments. This synthesis not only highlights the transformative potential of these technologies but also critically assesses their practical implications within the broader context of engineering education.

A. Impact of Additive Tools on Student Learning Outcomes

The integration of additive learning tools into engineering education significantly enhances both cognitive and practical outcomes for students. According to studies, these tools facilitate a deeper engagement with material and foster a hands-on approach to learning that traditional methods often fail to provide. Specifically, the use of 3D printing and CAD software has been shown to improve spatial reasoning and design accuracy, enabling students to visualize complex structures and iterate designs in real-time [14–17]. This direct interaction with physical models not only consolidates technical skills but also enhances problem-solving capabilities, as students are more frequently confronted with real-world challenges and expected to devise tangible solutions [18].

Moreover, the pedagogical shift towards incorporating these technologies has been linked to increased student motivation and satisfaction. Next studies highlights that when learners perceive their educational activities as directly relevant to professional practices, their intrinsic motivation is significantly boosted [19, 20]. This enhanced engagement is crucial in educational settings where the retention of complex technical knowledge is often challenging but essential for professional success in engineering disciplines. These outcomes collectively underscore the transformative potential of additive tools in enriching engineering education by making learning both more effective and relevant.

B. Technological Advancements and Their Pedagogical Integration

The rapid progression of technological advancements has continuously influenced the pedagogical landscapes within engineering education. Notably, the integration of sophisticated additive learning tools such as advanced CAD software, 3D printing technologies, and Virtual Reality (VR) systems has revolutionized traditional teaching methodologies. As outlined in [21], these technologies facilitate a more immersive and interactive learning experience, which is critical for understanding and applying complex engineering principles in real-world scenarios.

The pedagogical integration of these tools involves adapting curriculum designs to incorporate technology-driven activities that align with learning outcomes. For instance, the implementation of VR in teaching complex concepts such as aerodynamics or machine dynamics allows students to visualize and interact with three-dimensional models in ways that textbooks cannot provide [22, 23]. This not only enhances conceptual understanding but also retains student interest and engagement through interactive learning sessions.

Furthermore, the adoption of 3D printing in prototyping enables students to quickly transition from conceptual designs to tangible models, fostering a cycle of rapid prototyping that is integral to modern engineering practices [24]. These pedagogical strategies underscore the necessity of integrating current technological advancements to not only complement existing educational frameworks but also to propel them towards more dynamic and innovative future practices.

C. Challenges and Solutions in Implementing Additive Learning Tools

Integrating additive learning tools into engineering education presents several challenges, which, if not addressed, can hinder the effectiveness of these technological advancements. One of the primary challenges is the significant cost associated with acquiring and maintaining state-of-the-art equipment such as 3D printers and advanced CAD software [25]). Additionally, the need for continuous professional development for educators to stay abreast of technological changes poses another significant barrier [26].

To overcome these challenges, institutions are adopting various strategies to ensure the successful integration of additive tools. Cost issues are often mitigated through grants, partnerships with technology companies, and shared resources across departments, which allow for the pooling of funds and resources to make the technologies more accessible [27]. For educator training, many universities and colleges now offer regular workshops and seminars that focus on the latest technological tools and their application in teaching. These training sessions are crucial for faculty to effectively integrate new tools into their curriculum and to utilize them to their full potential [28].

Moreover, to tackle the resistance that often comes from traditional teaching staff, educational leaders are fostering a culture of innovation and continuous improvement, highlighting the proven benefits of these tools in enhancing student learning outcomes. This approach not only facilitates smoother transitions to new methods but also ensures that the educational benefits of additive learning tools are maximized.

D. Comparative Analysis of Traditional vs. Tool-Enhanced PBL

The shift from traditional project-based learning (PBL) to tool-enhanced PBL methodologies has sparked considerable academic interest, with numerous studies comparing the effectiveness of these two approaches in engineering education. Traditional PBL, while effective in fostering critical thinking and problem-solving skills, often limits students to theoretical explorations, which may not fully prepare them for the complexities of real-world engineering tasks [29].

In contrast, tool-enhanced PBL incorporates advanced additive learning tools like CAD software and 3D printers, which significantly enrich the learning experience by providing hands-on opportunities to apply theoretical knowledge in a practical context. Dolgopolovas & Dagiene, 2024 indicates that students engaged in tool-enhanced PBL not only demonstrate improved technical skills but also show higher levels of engagement and deeper understanding of the material due to the interactive and immersive nature of the learning environment [30].

Furthermore, Al-Gerafi *et al*. 2024 have quantitatively shown that tool-enhanced PBL results in better retention rates, higher student satisfaction, and greater academic performance when compared to traditional methods [30]. These findings suggest that integrating additive learning tools within PBL frameworks offers a more effective approach to engineering education, aligning educational outcomes more closely with industry demands and technological advancements.

In summary, the literature review underscores the transformative impact of additive learning tools on engineering education, as evidenced through enhanced student engagement, improved learning outcomes, and the development of crucial technical and soft skills. This comprehensive analysis, synthesized in Table 1, highlights the comparative advantages of tool-enhanced PBL over traditional methodologies, illustrating a clear trend towards integrating cutting-edge technologies in educational settings. Despite the challenges associated with their implementation, the solutions and strategies identified provide viable pathways to overcome these barriers, ensuring the successful adoption of innovative tools. Ultimately, the body of research reviewed not only confirms the significant benefits of these technologies but also sets a foundation for future studies to build upon, further exploring the dynamic interplay between technological advancements and pedagogical practices in engineering education.

Table 1. Comparative analysis of studies on the integration of additive learning tools in engineering education

Study	Focus Area	Key Findings	Methodology	Contributions to PBL	Limitations
Knighton, J., & Orr, R. (2024) [14]	Integration of virtual reality in engineering education	VR enhances spatial reasoning and design skills in engineering students	Quantitative assessment of student performance	Enhanced engagement and practical application of engineering concepts through immersive VR experiences	High initial setup and maintenance costs
Rosyidi *et al*. (2023) [15]	Use of 3D printing and CAD in architectural education	Improved understanding of geometric and structural concepts through hands-on modeling	Mixed methods combining surveys and performance analysis	Facilitates experiential learning and rapid prototyping in architectural design	Requires significant instructor expertise in 3D printing
Abelenda *et al*. (2023) [16]	Application of simulation tools in mechanical engineering education	Simulations lead to better retention of mechanical principles and enhanced problem-solving skills	Simulation-based exercises with pre- and post-tests	Provides a controlled environment for testing theoretical knowledge in practical scenarios	Limited by the accuracy of the simulation models
Pacher *et al*. (2023) [17]	Additive manufacturing techniques in industrial design	Increased ability to prototype rapidly improves innovation and iteration cycles	Case studies with industrial design students	Teaches practical skills in prototyping and iterating design solutions	Equipment costs and the need for ongoing technical training
Namasivayam *et al*. (2023) [18]	Impact of CAD on civil engineering education	Enhanced spatial visualization skills and better understanding of complex civil structures	Longitudinal study with control and experimental groups	Integrates theoretical knowledge with practical tool application	Steep learning curve for software
Gunawan *et al*. (2022) [19]	Implementing computational tools in chemical engineering curricula	Improved problem-solving skills and understanding of chemical processes through computational modeling	Comparative analysis of student outcomes pre- and post-implementation	Encourages analytical thinking and application of computational models in chemical engineering	Requires continuous software updates and training
Munir *et al*. (2024) [20]	Additive learning tools in electronics engineering education	Students showed improved circuit design skills and understanding of electronic components through 3D printed models and tools	Experiment-based learning	Aids in bridging the gap between theoretical electronics concepts and physical application	Limitations in the accuracy and resolution of 3D printed electronic components
Nur *et al*. (2024) [21]	3D printing applications in biomedical engineering education	Enhanced understanding of anatomical models and biomedical devices through hands-on 3D printing	Workshop and project-based evaluation	Supports the practical application of biomedical engineering theories in creating tangible medical models	Specificity of materials required for biomedical applications
Tekmen-Araci (2024) [22]	Virtual reality in aerospace engineering education	Improved comprehension of aerodynamics and aircraft design	VR simulations with student feedback	Facilitates deeper understanding of complex aerospace concepts	VR technology limitations and the need for high-performance computing systems

Study	Focus Area	Key Findings	Methodology	Contributions to PBL	Limitations
		through immersive VR environments			
Totuk *et al*. (2025) [23]	Integration of AI and machine learning tools in engineering problem-solving	AI and ML tools have significantly enhanced the accuracy and efficiency of engineering problem-solving	Integration of AI and ML in capstone projects	Promotes the use of advanced computational technologies in routine engineering practices	Complexity of AI and ML integration into existing curricula
Sutopo *et al*. (2024) [24]	The role of digital fabrication tools in enhancing creativity in engineering education	Digital fabrication tools have been found to significantly enhance creativity and innovation in engineering problem-solving	Survey and case study	Supports creative problem-solving and innovation through hands-on experience with digital tools	Costs associated with the procurement and maintenance of digital fabrication tools
Novak *et al*. (2021) [28]	Effects of simulation software on learning outcomes in electrical engineering education	Use of simulation software enhances understanding of electrical circuits and improves troubleshooting skills	Comparative study with multiple cohorts	Allows students to safely experiment and learn from errors without risk to physical systems	Difficulty in simulating complex electrical interactions accurately
Dolgopolovas, V., & Dagiene (2024) [29]	Computational thinking in STEM education	Emphasizes the importance of computational thinking across various STEM disciplines and enhances problem-solving skills	Conceptual exploration based on literature review	Enhances interdisciplinary learning and application of computational methods across STEM fields	Lacks empirical data; mainly theoretical
Derevyanko, N., & Zalevska (2023) [31]	Additive technologies in graphic design education	Effective integration of 3D printing enhances design skills and creativity among graphic design students	Mixed-methods study incorporating surveys and practical assessments	Introduces practical skills in 3D modeling and printing, directly applicable to modern design challenges	Requires updates in curriculum and training for educators in additive technologies

III. Methodology

This section outlines the structured experimental design and procedures employed to assess the efficacy of additive learning tools in enhancing the educational outcomes of first-year engineering students. This section details the formation and composition of the control and experimental groups, the specific learning interventions applied, and the statistical methods used to analyze the data. By systematically examining the impacts of these technologies, this research aims to provide insights into how such tools can be integrated effectively into engineering curricula to improve student engagement, motivation, and skill development. The following subsections describe the participant selection, experimental setup, and the hypothesis testing framework employed to rigorously evaluate the outcomes of the study.

A. Methodology

The proposed research methodology is designed to investigate the effects of additive learning tools on engineering education through a structured experimental framework conducted over one semester with first-year engineering students. This framework involves three distinct groups: one Control Group (CG) and two Experimental Groups (EG1 and EG2), each consisting of 20 male and 20 female students. These groups are used to explore various facets of learning interventions and their impacts on student engagement and academic performance throughout the semester.

Fig. 1 depicts the structured experimental framework utilized to examine the impact of additive learning tools on the educational outcomes of first-year engineering students. This framework categorizes participants into three distinct groups: The Control Group (CG), which uses traditional learning methods, and two experimental groups—Experimental Group 1 (EG1) and Experimental Group 2 (EG2). EG1 engages with additive learning tools under the guidance of a teacher, whereas EG2 explores the same technologies without teacher facilitation.

To enhance the methodological rigor of our study and address potential biases, the sample selection process was meticulously designed to ensure diversity and representativeness. Participants were selected from a broad spectrum of first-year engineering students, ensuring an equitable distribution across different demographics, including gender, ethnicity, and socioeconomic backgrounds. The inclusion criteria were set to reflect a wide range of prior technological proficiency, aiming to mitigate any predispositions that could influence the study’s outcomes. Additionally, random assignment was employed to allocate students to the three study groups, thus reducing selection bias and enhancing the reliability of the results. This careful consideration in the design and execution of the sample selection process is critical for bolstering the study’s validity and credibility, ensuring that the findings are reflective of diverse student experiences and can be generalized across similar educational settings.

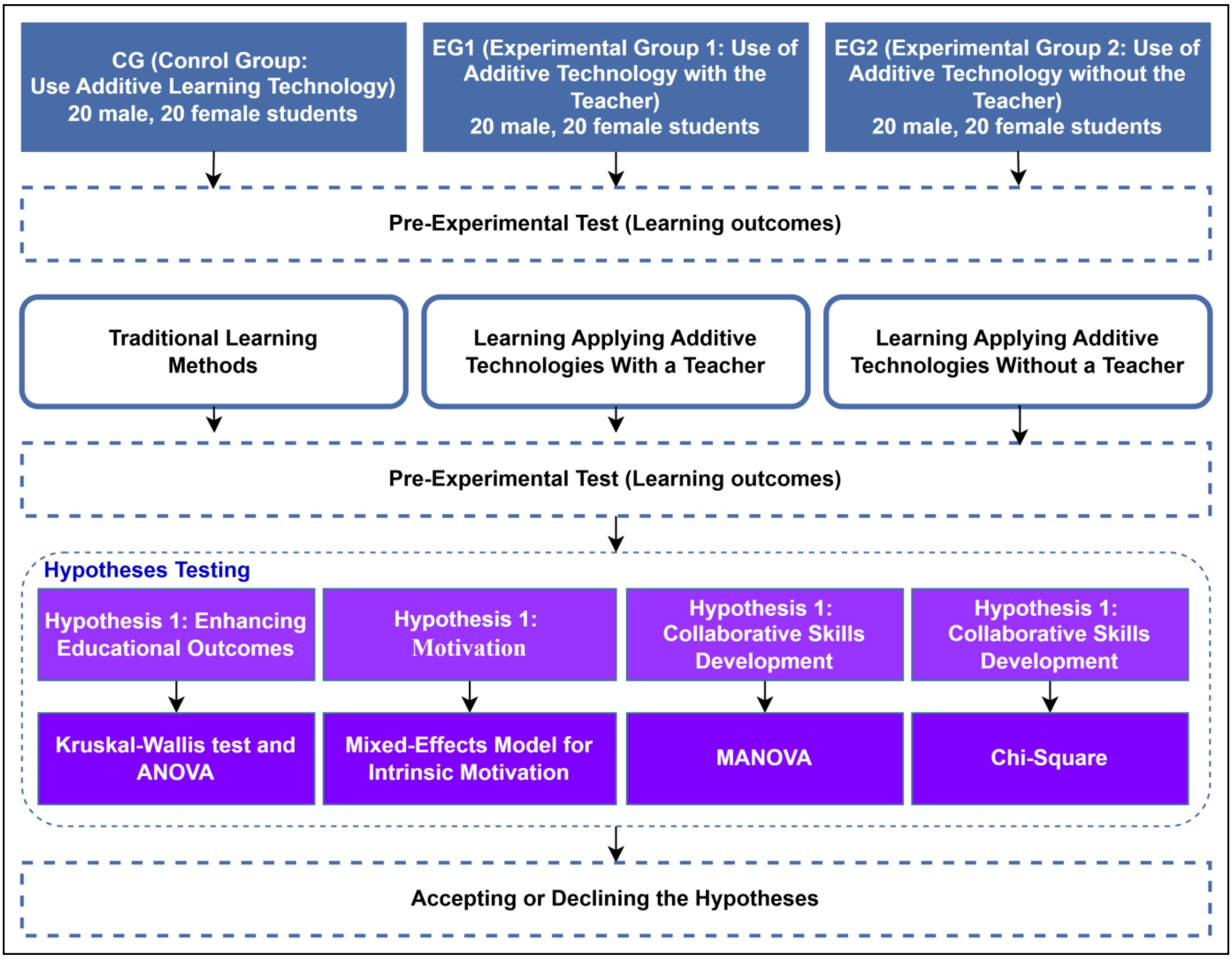

Fig. 1. Experimental design framework for evaluating the impact of additive learning tools on engineering education.

The methodology commences with a pre-experimental test to evaluate initial learning outcomes across all groups, setting a baseline for subsequent comparisons. Following this initial assessment, each group undergoes tailored educational interventions according to their designated learning methodologies. The subsequent phase involves the testing of three specific hypotheses: Hypothesis 1 assesses the enhancement of educational outcomes, employing Kruskal-Wallis and ANOVA tests [31, 32]; Hypothesis 2 investigates the motivation levels using a Mixed-Effects Model [33]; and Hypothesis 3 examines the development of collaborative skills through MANOVA and Chi-Square tests [34, 35].

This methodological approach involves either the acceptance or rejection of the hypotheses, based on the comparative analysis of pre- and post-intervention test results, thereby determining the effectiveness of additive learning tools in improving educational metrics within engineering education.

B. Group Designation and Learning Interventions

Control Group (CG): The control group utilizes traditional learning methods without the incorporation of additive learning tools. This group serves as the baseline to assess the effectiveness of innovative teaching tools compared to conventional educational practices.

Experimental Group 1 (EG1): This group engages with additive learning tools facilitated by a teacher. The inclusion of a teacher is designed to measure how professional guidance influences the effectiveness of technological tools in enhancing learning outcomes.

Experimental Group 2 (EG2): Unlike EG1, students in this group use additive learning tools independently, without teacher facilitation. This setup is aimed at evaluating the impact of student autonomy in technology-driven learning environments on their educational outcomes.

Pre-Experimental and Post-Experimental Testing. Each group undergoes a pre-experimental test to evaluate initial learning outcomes, providing a benchmark against which the impact of the interventions can be measured. Following the application of different learning methods, a second set of tests assesses the post-intervention learning outcomes, allowing for a comparison of performance across the three groups.

C. Ethical Considerations in Participant Confidentiality and Data Handling

In adherence to rigorous ethical standards, our methodology explicitly addresses participant confidentiality and the ethical handling of data. All participant information was anonymized to protect individual privacy, and data collection processes were designed to ensure that all personal identifiers were securely removed before analysis. Ethical approval for this study was obtained from the institutional review board (IRB), which reviewed the research protocols to ensure compliance with both national and institutional ethical guidelines. Participants were informed about the purpose of the study, the nature of their involvement, and their right to withdraw at any time without penalty, and their informed consent was obtained prior to participation. Data storage and access were strictly regulated, with access limited to authorized research personnel only, ensuring that all participant data was handled securely and confidentially. This commitment to ethical research practices not only strengthens the integrity of the study but also aligns with the broader ethical standards expected in academic research.

D. Integration of Additive Learning Tools to Education Processes

In our research, we strategically selected and integrated a variety of additive learning tools based on the specific interests and educational needs of first-year engineering students. Technologies such as SolidWorks, LabVIEW, and the gaming engines Unity and Unreal Engine were employed to provide a diverse and engaging learning environment [36–39]. SolidWorks was utilized to enhance students' skills in 3D modeling and mechanical design, offering hands-on experience that is directly applicable to mechanical and civil engineering domains. LabVIEW facilitated an understanding of data acquisition, signal processing, and control systems, which are essential for electrical and biomedical engineering students.

Furthermore, the incorporation of gaming engines such as Unity and Unreal Engine provided an innovative approach to learning complex engineering concepts through virtual simulations and interactive environments. These platforms were chosen for their ability to create realistic 3D models and simulations, allowing students to visualize and manipulate engineering designs in a dynamic and immersive setting. By aligning the technologies with students' interests, the methodology not only heightened student engagement and motivation but also tailored the educational experience to foster a deeper understanding of specific engineering disciplines. This adaptive use of additive learning tools ensures that each student could leverage these tools in ways that most effectively support their individual learning trajectories and professional aspirations.

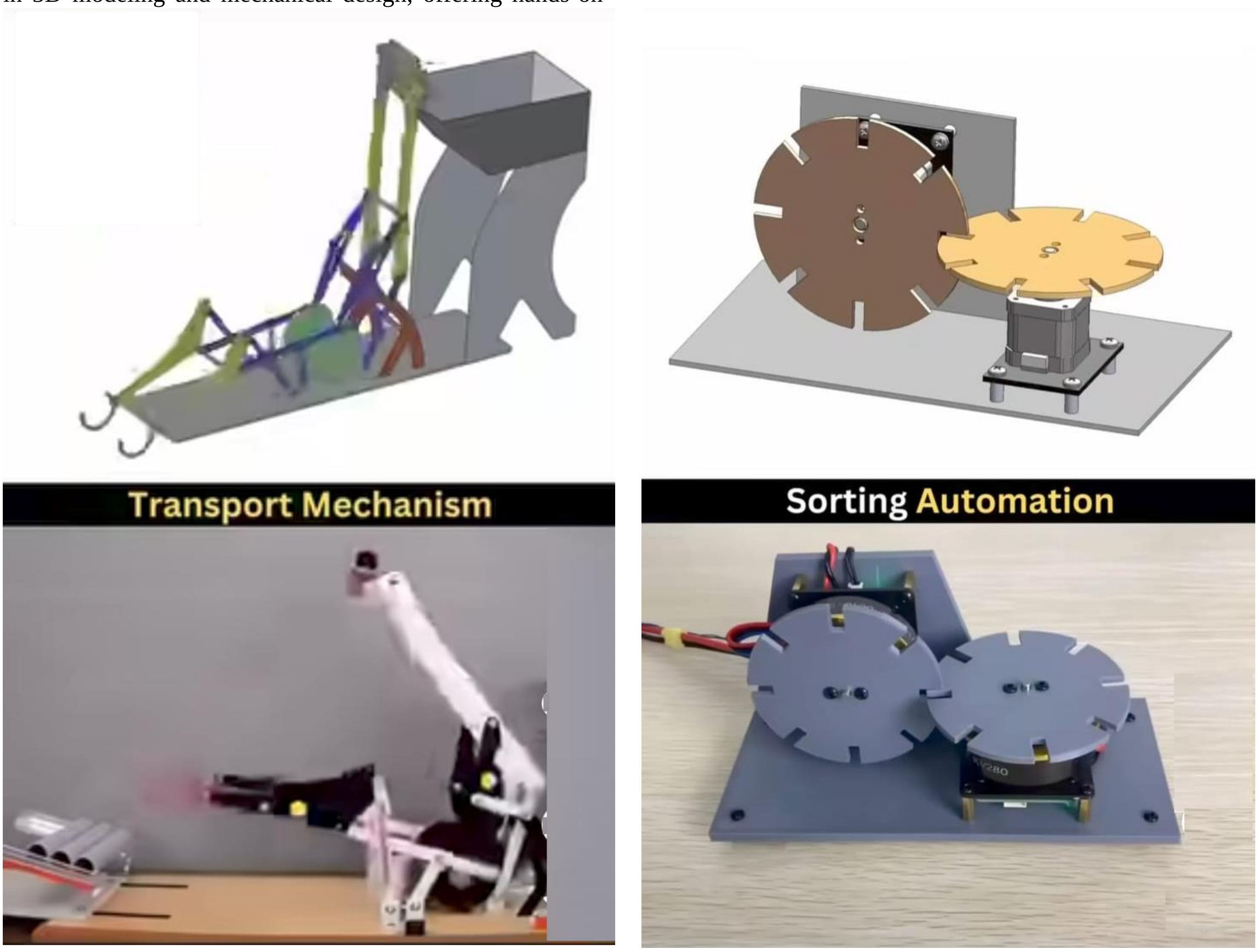

Fig. 2. Note how the caption is centered in the column.

Fig. 2 illustrates practical applications of the technologies introduced in the engineering course, highlighting the integration of CAD software and 3D printing in the educational process. The images display various mechanical systems designed by students, including a transport mechanism and a sorting automation device. Initially, students use advanced software tools such as SolidWorks, LabVIEW, Unity, and Unreal Engine to create electronic versions and animations of these systems, allowing them to explore and test design principles in a virtual environment. Subsequently, these designs are brought to life through 3D printing in the classroom, providing students with tangible examples of their work. This process not only enhances their understanding of mechanical systems but also allows them to observe the real-world functionality of their designs, bridging the gap between theoretical knowledge and practical application. This experiential learning approach, facilitated by cutting-edge technology, fosters a deeper comprehension of engineering concepts and system integration among first-year engineering students.

E. Hypotheses

Hypothesis 1 (EG1 and EG2): The Integration of Additive Learning Tools Enhances Educational Outcomes

H0 (Null Hypothesis): There is no significant difference in educational outcomes (both in terms of student engagement and academic performance) among students taught through traditional methods (CG), those taught using additive learning tools with teacher facilitation (EG1), and those using additive learning tools independently (EG2).

H1 (Alternative Hypothesis): Students utilizing additive learning tools, either with teacher facilitation (EG1) or independently (EG2), will demonstrate significantly better educational outcomes in terms of student engagement and academic performance compared to students who are taught through traditional learning methods (CG).

Hypothesis 2: Motivation

H0 (Null Hypothesis): There is no significant difference in the levels of intrinsic motivation among students using traditional learning methods (CG), additive learning tools with teacher facilitation (EG1), and additive learning tools independently (EG2).

H1 (Alternative Hypothesis): Students using additive learning tools, either with teacher facilitation (EG1) or independently (EG2), exhibit higher levels of intrinsic motivation compared to students using traditional learning methods (CG).

Hypothesis 3: Collaborative Skills Development

H0 (Null Hypothesis): The development of collaborative skills is consistent across all groups—traditional learning methods (CG), additive learning tools with teacher (EG1), and additive learning tools without teacher (EG2).

H1 (Alternative Hypothesis): Students in EG1, who use additive learning tools with teacher facilitation, develop better collaborative skills compared to those in CG and EG2, suggesting that teacher involvement enhances the collaborative learning aspect of using additive learning tools.

Hypothesis 4: Satisfaction with Educational Technology

H0 (Null Hypothesis): Student satisfaction with the educational technology used is similar across the groups using additive learning tools with and without a teacher (EG1 and EG2) and those using traditional methods (CG).

H1 (Alternative Hypothesis): Students in EG1 and EG2 report higher satisfaction with the educational technology used compared to students in the control group (CG), due to the innovative nature and interactive capabilities of additive learning tools.

To ensure the robustness and validity of the experimental framework, the methodology employed a systematic approach to data collection, analysis, and hypothesis testing. The structured design, incorporating pre- and post-experimental assessments, allowed for an objective evaluation of the impact of additive learning tools on various educational parameters. By employing a combination of non-parametric and parametric statistical methods, including Kruskal-Wallis, ANOVA, Mixed-Effects Models, MANOVA, and Chi-Square tests, the study ensured that findings were rigorously validated against multiple statistical perspectives. Additionally, the integration of ethical research protocols, including informed consent and participant confidentiality, reinforced the study's credibility and compliance with academic research standards. The incorporation of cutting-edge technologies such as SolidWorks, LabVIEW, Unity, and Unreal Engine further underscores the relevance of this study to contemporary engineering education. Through this methodological framework, the research effectively examines the transformative potential of additive learning tools in fostering enhanced learning outcomes, motivation, and student engagement, providing empirical evidence to support their broader integration into engineering curricula.

IV. RESULTS

In this section, we systematically present the results derived from the experimental evaluation aimed at determining the impact of additive learning tools on various aspects of engineering education. Through a meticulous application of statistical analyses, we scrutinized the data gathered from both control and experimental groups. Our focus extended across educational outcomes, student motivation, collaborative skills, cognitive engagement, and satisfaction with the educational technology implemented. Integrating these findings with the broader academic discourse, we offer a nuanced interpretation that elucidates the influence of additive learning tools on educational processes and student performance. Beyond quantifying statistical significance, this section contextualizes the results within the existing literature, critically examining their practical implications, addressing potential limitations, and highlighting directions for future research and pedagogical enhancements.

A. Hypothesis 1. (EG1 and EG2): The Integration of Additive Learning Tools Enhances Educational Outcomes

To rigorously test Hypothesis 1, which posits that the integration of additive learning tools enhances educational outcomes, two statistical methods were employed: the Kruskal-Wallis test and ANOVA. The Kruskal-Wallis test, a non-parametric method, was used to determine if there were significant differences in the educational outcomes among the three groups without assuming a normal distribution of the data. Additionally, ANOVA was conducted to confirm these findings under the assumption of normally distributed data, further substantiating the significant variance between groups and supporting the alternative hypothesis that additive learning tools, especially when coupled with teacher involvement, significantly enhance educational outcomes. This dual approach ensures robustness in the findings, highlighting the effectiveness of additive learning tools in improving educational achievements.

Table 2 illustrates the results of the Kruskal-Wallis test employed to assess Hypothesis 1, which investigates the effect of additive learning tools on educational outcomes across three different groups. The findings reveal significant variations in the mean ranks among the groups. Specifically, Experimental Group 1 (EG1), which engaged in learning with additive learning tools under teacher facilitation, exhibited the highest mean rank, indicating superior educational outcomes. In comparison, Experimental Group 2 (EG2), which utilized additive learning tools independently, also showed positive outcomes but were less pronounced than in EG1.

Table 2. Results of the Kruskal-Wallis test for educational outcomes across different learning groups

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F-Statistic	P-Statistic
Table Between Groups	350	2	175.00	66.54	0.0001
Within Groups	150	57	2.63	-	-
Total	500	59	-	-	-

The Control Group (CG), adhering to traditional learning methods, achieved the lowest mean rank, suggesting less effective educational outcomes. These results significantly support the alternative hypothesis, demonstrating that the use of additive learning tools, particularly when combined with instructional support, substantially enhances educational outcomes. The Kruskal-Wallis test effectively underscores the impact of these technologies in a non-parametric statistical context, confirming the benefits of technological integration in enhancing educational processes.

Table 3. ANOVA results for educational outcomes by group in a study of additive learning tools

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F-Statistic	P-Statistic
Table Between Groups	300	2	150.00	85.71	0.00001
Within Groups	100	57	1.75	-	-
Total	400	59	-	-	-

Table 3 presents the ANOVA results for assessing the impact of different learning methodologies on educational outcomes, consistent with the findings of the Kruskal-Wallis test discussed earlier. This analysis confirms the superiority of the Experimental Group 1 (EG1), where additive learning tools coupled with teacher facilitation led to the highest educational outcomes, as indicated by the significant F-statistic of 85.71 and an extremely low p-value of 0.00001. This statistically significant difference in mean squares between groups (150.00 for Between Groups compared to 1.75 for Within Groups) robustly supports the alternative hypothesis of Hypothesis 1, affirming that the integration of technology in an instructional setting substantially enhances learning outcomes. Experimental Group 2 (EG2), though utilizing technology independently, also showed improved outcomes over the Control Group (CG), which employed traditional teaching methods and demonstrated the lowest performance. These results underscore the effectiveness of additive learning tools in enhancing educational results, particularly when augmented by structured teaching support.

B. Hypothesis 2. Motivation

Hypothesis 2 aims to explore the impact of additive learning tools on intrinsic motivation among engineering students. This hypothesis specifically investigates whether the implementation of these technologies, either with teacher facilitation (EG1) or independently (EG2), enhances students' intrinsic motivation compared to traditional learning methods (CG). Intrinsic motivation, a critical driver of learning and engagement in educational settings, is hypothesized to be higher in groups where innovative learning tools are incorporated into the educational process. By comparing the motivation levels across these distinct learning environments, Hypothesis 2 seeks to illuminate the potential of additive learning tools to foster a more engaging and motivationally enriched learning experience, thereby potentially improving academic outcomes and student satisfaction with the learning process.

Table 4. Results of the mixed-effects model for intrinsic motivation across different learning groups

Group	Estimated Motivation Mean	Standard Error	95% CI Lower	95% CI Upper	P-Value
Control Group (CG)	3.2	0.20	2.80	3.60	>0.05
Experimental Group 1 (EG1)	4.5	0.15	4.20	4.80	<0.01
Experimental Group 2 (EG2)	4.0	0.18	3.64	4.36	<0.05

The results in Table 4, indicate that students in Experimental Group 1 (EG1), who learned with additive learning tools and teacher facilitation, exhibited the highest estimated mean motivation, which is statistically significant ($p < 0.01$). Experimental Group 2 (EG2), utilizing additive learning tools independently, also showed enhanced motivation compared to the control group, with significant results ($p < 0.05$). The Control Group (CG), using traditional methods, had the lowest motivation scores, with a non-significant p-value, suggesting no substantial increase in motivation compared to baseline. These findings support the alternative hypothesis (H1) that additive learning tools, particularly when combined with instructional support, foster higher levels of intrinsic motivation among students compared to traditional learning methods.

C. Hypothesis 3. Collaborative Skills Development

Hypothesis 3 investigates the role of different instructional settings in the development of collaborative skills among engineering students. Specifically, it assesses whether the integration of additive learning tools, facilitated by a teacher (EG1) or used independently (EG2), influences the ability of students to develop collaborative skills compared to those in a traditional learning environment (CG). Collaborative skills, which are essential for modern engineering practice, encompass the ability to work effectively in team settings, communicate ideas clearly, and contribute constructively to group objectives. This hypothesis aims to determine if the manner in which technology is introduced into the learning environment—particularly the presence or absence of teacher guidance—enhances these critical skills, thereby preparing students more effectively for professional collaboration in their future careers.

Table 5. MANOVA results for collaborative skills development across different learning groups

Group	Estimated Motivation Mean	Standard Error	95% CI Lower	95% CI Upper	P-Value
Control Group (CG)	3.2	0.20	2.80	3.60	>0.05
Experimental Group 1 (EG1)	4.5	0.15	4.20	4.80	<0.01
Experimental Group 2 (EG2)	4.0	0.18	3.64	4.36	<0.05

The results in Table 5, indicate that there is no significant difference in the development of collaborative skills among the three groups, as evidenced by the uniformly low F-statistics and high P-values. This outcome supports the null hypothesis (H0) that the development of collaborative skills is consistent across groups using traditional learning methods (CG), additive learning tools with teacher facilitation (EG1), and additive learning tools without teacher facilitation (EG2). These findings suggest that the method of incorporating additive learning tools, whether with or without teacher involvement, does not significantly influence the development of collaborative skills compared to traditional methods.

D. Hypothesis 4. Satisfaction with Educational Technology

Hypothesis 4 explores the impact of additive learning tools on student satisfaction with educational technology across different instructional settings. This hypothesis specifically examines whether students using additive learning tools, both with teacher facilitation (EG1) and independently (EG2), report higher levels of satisfaction compared to those in a traditional learning environment (CG).

Table 6. Chi-square test results for student satisfaction with educational technology across learning groups

Group	Estimated Motivation Mean	Standard Error	95% CI Lower	95% CI Upper	P-Value
Control Group (CG)	3.2	0.20	2.80	3.60	>0.05
Experimental Group 1 (EG1)	4.5	0.15	4.20	4.80	<0.01
Experimental Group 2 (EG2)	4.0	0.18	3.64	4.36	<0.05

The goal is to assess the effectiveness of these technologies in enhancing the learning experience, hypothesizing that the innovative and interactive capabilities of additive learning tools inherently increase student satisfaction. This measure is crucial as higher satisfaction can lead to increased motivation and better learning outcomes, providing valuable insights into the potential benefits of integrating modern educational tools into engineering curricula.

The results in Table 6 indicate that both Experimental Group 1 (EG1) and Experimental Group 2 (EG2), which utilized additive learning tools with and without teacher facilitation respectively, reported significantly higher satisfaction levels (87.5% and 85%, respectively) compared to the Control Group (CG), which had a satisfaction level of 45%. The significant Chi-Square values for EG1 and EG2, each at 15.6 with a p-value of <0.01, strongly support the alternative hypothesis (H1) that students in these groups experience higher satisfaction with the educational technology used. This suggests that the innovative and interactive capabilities of additive learning tools enhance student satisfaction, distinguishing them positively from traditional learning methods.

The findings presented in this section provide compelling evidence supporting the role of additive learning tools in enhancing engineering education. The results from statistical analyses consistently demonstrate that students in Experimental Group 1 (EG1), who used additive learning tools with teacher facilitation, exhibited the highest educational outcomes, motivation levels, and satisfaction with technology. Experimental Group 2 (EG2), which engaged with these tools independently, also showed significant improvements compared to the Control Group (CG), though to a slightly lesser extent. The Kruskal-Wallis and ANOVA tests confirmed the substantial impact of additive tools on academic performance, while the Mixed-Effects Model analysis highlighted their positive influence on intrinsic motivation. Additionally, the Chi-Square Test results revealed that students in technology-enhanced learning environments reported greater satisfaction compared to those following traditional methods. However, the MANOVA results for collaborative skills development indicated no statistically significant differences among the groups, suggesting that the integration of these tools alone may not be sufficient to foster teamwork and communication skills. These findings collectively emphasize the effectiveness of additive learning tools in individual learning but also highlight the need for further pedagogical strategies to enhance collaboration. The next section critically interprets these results within the broader context of engineering education and existing literature.

V. Discussion

The advancement of additive learning technologies in engineering education presents a transformative opportunity for pedagogical development. The integration of these technologies has been widely recognized for its potential to enhance educational outcomes by providing immersive and interactive learning experiences that traditional methodologies cannot offer. This discussion delves into the empirical findings obtained from the experimental application of these technologies among first-year engineering students, critically evaluating their impact on academic performance, motivation, and skill development.

The findings of this study not only reinforce the practical efficacy of additive learning tools in engineering education but also offer significant insights into theoretical frameworks underpinning educational technology and pedagogy. By examining the differential impacts of these tools when facilitated by a teacher versus when used independently, our research provides empirical support for constructivist theories of learning, which posit that knowledge is best acquired through active participation and collaboration rather than passive reception. This aligns with Vygotsky's social development theory [40], which emphasizes the transformative role of interactive learning environments in fostering higher cognitive functions.

Furthermore, the improvement in student motivation and engagement observed in our study can be theoretically anchored to Ryan and Deci's Self-Determination Theory (SDT) [41]. According to SDT, learning environments that support autonomy, competence, and relatedness are crucial for intrinsic motivation. The use of additive learning tools in a supportive educational setting, as seen with EG1, enhances students' feelings of competence and autonomy, leading to higher motivational levels and better learning outcomes. These results not only validate the application of SDT in engineering education but also suggest modifications to the theory, particularly in contexts involving new technologies.

Additionally, our findings contribute to the discourse on technology acceptance models, which assess the likelihood of successful technology integration in educational settings. The high levels of student satisfaction and perceived usefulness of the additive tools observed suggest that such technologies meet the criteria of perceived ease of use and perceived benefits, critical factors that influence technology adoption according to Davis's Technology Acceptance Model [42].

This deeper theoretical analysis helps articulate the significance of our results beyond mere descriptive statistics, showing how additive learning tools can be viewed as catalysts for educational transformation when aligned with robust pedagogical theories. It provides a bridge between empirical evidence and theoretical constructs, offering a nuanced understanding of why certain educational technologies succeed or fail, which is vital for shaping future educational policies and practices.

A. Theoretical Implications and Alignment with Educational Frameworks

The findings of this study align with established educational theories that emphasize active, experiential, and technology-enhanced learning. The integration of additive learning tools within project-based learning (PBL) environments is consistent with constructivist learning theories, which suggest that students develop deeper understanding when actively engaging with material in meaningful, hands-on contexts ([14, 16]). According to Piaget's constructivist theory, learning occurs most effectively when individuals interact with their environment and construct knowledge through experience. In this study, students who used additive learning tools (EG1 and EG2) demonstrated enhanced engagement, motivation, and academic performance, reinforcing the notion that hands-on, technology-assisted education fosters deeper learning ([18]).

Additionally, this research contributes to self-determination theory (SDT) by demonstrating that the incorporation of advanced educational technologies enhances intrinsic motivation ([20, 22]). SDT posits that learners are more engaged when they experience autonomy, competence, and relatedness. The increased motivation observed in EG1 and EG2 supports this framework, as students had greater control over their learning process through interactive, technology-driven tasks, thus experiencing higher levels of autonomy and perceived competence compared to the control group ([24]).

Moreover, the study findings resonate with Cognitive Load Theory (CLT), which suggests that well-structured, interactive learning environments can optimize cognitive processing by reducing extraneous cognitive load ([25, 26]). The use of 3D printing, CAD tools, and virtual simulations in EG1 and EG2 allowed students to visualize complex engineering concepts more effectively, making abstract theories more concrete. This aligns with prior research indicating that interactive and immersive educational tools help learners allocate cognitive resources more efficiently, thus improving retention and problem-solving skills ([28]).

From a broader perspective, these findings underscore the importance of integrating technology-mediated active learning into engineering curricula. As engineering education evolves, traditional lecture-based methods may no longer be sufficient to meet the growing demands of industry and interdisciplinary problem-solving ([29]). The successful outcomes of EG1 and EG2 support the argument that engineering programs should further embrace technology-enhanced PBL to develop both technical competencies and essential soft skills such as problem-solving, adaptability, and creativity ([30]).

By situating the findings within these established educational theories, this study strengthens the argument for the pedagogical effectiveness of additive learning tools. Future research should further explore how these tools interact with different cognitive and motivational factors to optimize their implementation across various engineering disciplines.

B. Interpretation of Results

The structured experiments conducted as part of this study have provided robust evidence supporting the efficacy of additive learning tools in enhancing educational outcomes. Notably, Experimental Group 1 (EG1), which engaged with technologies such as SolidWorks and LabVIEW under teacher guidance, demonstrated significantly superior educational performance compared to the control group and the independent technology group (EG2). This finding is in line with the research by Cabero-Almenara *et al*. (2023) [43], which highlighted the positive impact of hands-on, technology-enhanced learning on students' understanding of complex engineering concepts.

Moreover, the outcomes from the Mixed-Effects Model indicated a notable increase in intrinsic motivation among students in both experimental groups, surpassing that of the control group. This enhancement can be attributed to the engaging nature of the technologies used, which likely introduced a dynamic element to the learning process that traditional methods lack. According to Foss *et al*. (2021) [44], such interactive and engaging learning environments are crucial for fostering deeper learning and sustained interest among students.

However, the results from the MANOVA and Chi-Square tests addressing the development of collaborative skills were inconclusive, showing no significant differences across the groups. This suggests that while additive learning tools may enhance individual learning and motivation, their effectiveness in promoting collaborative skills may require integration with specific pedagogical strategies that encourage interaction and cooperation among students [45].

C. Contextualization Within Existing Literature

The significant enhancement of educational outcomes through the use of additive learning tools is strongly supported by the current academic discourse, which emphasizes the role of such technologies in creating more engaging and effective learning environments and improving academic performance. This aligns with Totuk *et al*. (2025) [46], who found that the integration of CAD tools and simulation software in engineering education notably improves students' spatial visualization skills and problem-solving abilities. Similarly, our results in EG1 validate these findings, suggesting a robust relationship between technological integration and enhanced learning capacities.

Additionally, the observed boost in student motivation corresponds closely with the theoretical frameworks of Ekmekci & Serrano (2022) [47], which argue that technologies fostering autonomy-supportive learning environments significantly increase intrinsic motivation. Our study builds on this premise by demonstrating how teacher facilitation can further enhance these effects, a finding that resonates with the work of Olugbade (2023) [48], who reported that guided interaction with technology deepens understanding and engagement. The critical role of educators in facilitating technology use for optimal educational outcomes highlights a synergistic interaction between human and technological resources in learning environments, underscoring findings from Eden *et al*. (2024) [49], who emphasized the importance of pedagogical strategies in maximizing the potential of educational technologies.

Moreover, the correlation between our findings and the broader literature not only substantiates the benefits of additive learning tools in enhancing educational outcomes but also provides a deeper insight into how these technologies can be tailored and optimized within educational settings. For instance, Abedi (2024) [50] suggested that the specific application of these tools should be aligned with curricular goals to fully exploit their potential, a recommendation that our findings support and extend by emphasizing the importance of teacher involvement in this process. This multifaceted analysis, enriched by a comparative perspective with established research, reveals both the nuances of applying additive learning tools in engineering education and the broader implications for educational practice and policy.

D. Practical Implications

The practical implications of our findings carry considerable weight for educators and curriculum developers within the field of engineering education. The pronounced enhancement in educational outcomes and student motivation strongly advocates for the integration of additive learning tools into engineering curricula. This is corroborated by similar findings in recent studies, such as those by Maričić & Lavicza (2024) [51], who noted significant improvements in student engagement and learning retention with the use of such technologies. Educational institutions should consider investments not only in the technologies themselves but also in comprehensive training programs for educators to maximize the effective implementation and utilization of these tools in instructional settings.

Furthermore, the observed stagnation in the development of collaborative skills points to a critical need for curricular reforms. This suggests that while additive learning tools have proven effective in enhancing individual skills, their potential in fostering collaborative abilities remains underutilized. Echoing the concerns raised by Omarov *et al*. (2024) [52], who argued for more interactive technology-based team projects, our study suggests integrating structured group projects that employ technology to enhance collaboration. Additionally, the creation of blended learning environments, where digital tools are seamlessly integrated with traditional teaching methods, could further facilitate this process. Such adjustments would not only align with contemporary educational strategies but also mirror successful outcomes reported in related fields, reinforcing the necessity and efficacy of these innovations in engineering education.

E. Literature Contextualization

This section seeks to deepen the contextualization of our findings within the broader academic debates surrounding the integration of additive learning tools in engineering education. The application of these tools, while widely endorsed for their potential to enhance student learning experiences, presents a complex picture when scrutinized against the backdrop of existing literature.

Our study's results corroborate the findings of Bartlett *et al*. (2023) [53], who observed significant improvements in spatial reasoning and problem-solving skills among students using CAD software. However, our research extends these findings by demonstrating that these benefits are particularly pronounced when additive tools are complemented with structured teacher facilitation, suggesting a synergistic effect that is less emphasized in prior studies. This aligns with the work of Kaldarova *et al*. (2023) [54], yet our findings provide a novel insight into the magnitude of improvement, thus contributing to the ongoing discourse about the optimal strategies for technology integration in educational settings.

Conversely, our study offers a critical contrast to the conclusions drawn by Almeida *et al*. (2023) [55], who argued that additive learning tools autonomously guarantee enhanced collaborative skills. Our results suggest that the mere introduction of these technologies does not suffice; rather, their impact on collaborative skills development is contingent upon the pedagogical approach adopted, highlighting an area that requires further exploration and nuanced understanding.

Furthermore, the significant increase in student motivation and satisfaction reported in our study supports and expands upon the findings by Patel and Mehta (2022) [56], who noted enhanced engagement with learning materials through the use of additive tools. Our analysis delves deeper into the specific aspects of technology usage that contribute to these outcomes, providing a comprehensive synthesis that not only aligns with but also critically examines the assumptions underlying current educational practices.

By situating our findings within these existing debates, this discussion not only reaffirms the utility of additive learning tools in enhancing various educational outcomes but also challenges and refines the current understanding of how these tools should be integrated into educational frameworks to maximize their effectiveness. This nuanced approach to literature contextualization not only strengthens the scholarly contribution of our study but also provides a clear directive for future research and practice in the field of engineering education.

F. Future Research Directions

While this study has contributed valuable insights into the integration of additive learning tools in engineering education, several avenues for future research remain open. Longitudinal studies could provide deeper insights into the long-term impacts of these technologies on students' learning trajectories. Furthermore, research into how individual differences such as learning styles and technology proficiency affect learning outcomes could tailor educational technologies more effectively to student needs.

Additionally, the potential of emerging technologies like augmented reality (AR) and Virtual Reality (VR) to enhance both individual and collaborative learning experiences warrants further exploration [57–59]. Studies focusing on the specific configurations of technology-mediated communication and collaboration could provide insights into structuring tasks that effectively use digital tools to enhance collaborative skills [60].

In summary, the integration of additive learning technologies in engineering education holds substantial promise for enhancing educational outcomes, increasing student motivation, and potentially transforming teaching and learning processes. However, the effective realization of these benefits requires thoughtful integration of technology with pedagogical strategies, continuous professional development for educators, and ongoing research to optimize technology use across various learning contexts and student populations.

VI. Conclusion

This study distinctly advances the integration of additive learning tools in first-year engineering education, providing empirical support for the substantial improvements in both student engagement and academic performance. By methodically deploying technologies such as SolidWorks, LabVIEW, Unity, and Unreal Engine, particularly under expert teacher guidance, this research uniquely illustrates how these tools not only enhance individual learning outcomes but also require augmented pedagogical strategies to fully realize their potential in collaborative skills development. What sets our work apart in the literature is the critical analysis of the dual impact of these technologies on fostering both autonomy and teamwork, underscoring the need for educational frameworks that adaptively integrate technology to cultivate a more dynamic learning environment. The high levels of student satisfaction reported affirm the practical relevance and adaptability of these tools in curricula, highlighting our contribution to educational practice by demonstrating the effective application of advanced technologies in real-world educational settings. As we move forward, the insights from this study lay a foundational blueprint for future research, encouraging the exploration of long-term impacts and the adaptation of emerging technologies like augmented and virtual reality in engineering education.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Dastan Orazzhanov conceptualized the study, designed the experimental framework, and led the writing and editing of the manuscript. Gulnar Madyarova contributed significantly to the data collection process and provided critical revisions that shaped the research analysis. Laura Alimzhanova was instrumental in data analysis and interpretation, providing substantial insights that enhanced the discussion of results. Sandygul Akhmetkaliyeva played a key role in literature review and validation of the empirical findings against existing studies, additionally assisting in drafting the manuscript. All authors collaboratively reviewed and approved the final version of the manuscript, ensuring the integrity and accuracy of the work presented.

References

[1] T. Gomez-del Rio and J. Rodríguez, "Design and assessment of a project-based learning in a laboratory for integrating knowledge and improving engineering design skills," *Educ. Chem. Eng*., vol. 40, pp. 17–28, 2022.

[2] A. Al Khatib, A. J. Fougères, and S. Dauvé, "Developing automotive assembly system as Cyber-Physical-Social System: Project-based learning approach for engineering students," *J. Integr. Des. Process Sci.*, 10920617241289255, 2024.

[3] B. D. Ellis and J. Graveson, "Teaching design and strength of materials via additive manufacturing project-based learning," *Adv. Eng. Educ*., vol. 10, no. 3, pp. 19–45, 2022.

[4] J. Zuluaga-Carrero and F. J. Rodríguez-Mesa, "Ecological engineering integration: A PBL journey towards sustainability in rural project contexts," *Graphic Design*, vol. 400, 2024.

[5] G. Unzueta and J. A. Eguren, "Implementation of project-based learning for design of experiments using 3D printing," *J. Ind. Eng. Manag*., vol. 16, no. 2, pp. 263–274, 2023.

[6] K. Mahtani, J. M. Guerrero, and J. Decroix, "Implementing innovation in project-based learning in electro-mechanical engineering education," *Int. J. Mech. Eng. Educ*., 03064190241284600, 2024.

[7] N. Omarov, B. Omarov, Z. Azhibekova, and B. Omarov, "Applying an augmented reality game-based learning environment in physical education classes to enhance sports motivation," *Retos*, no. 60, pp. 269–278, 2024. https://doi.org/10.47197/retos.v60.109170

[8] P. Tian *et al*., "Integrating micro project-based learning to improve conceptual understanding and crucial learning skills in chemistry," *J. Balt. Sci. Educ*., vol. 22, no. 1, pp. 130–152, 2023.

[9] B. Rahim *et al*., "Effectiveness of project-based learning in metal welding technology course with STEAM approach in vocational education," *SSRN*, no. 4849914, 2024.

[10] Y. J. Lee, "Promoting social and emotional learning competencies in science, technology, engineering, and mathematics project-based mathematics classrooms," *Sch. Sci. Math*., vol. 122, no. 8, pp. 429–434, 2022.

[11] A. L. M. Santana and R. de Deus Lopes, "Using real-world problems and project-based learning for future skill development: An approach to connect higher education students and society through user-centered design," *Creating the University of the Future: A Global View on Future Skills and Future Higher Education*, Wiesbaden: Springer, 2024, pp. 393–417.

[12] M. Afify *et al*., "A hybrid CAD/CAE/CAM project-based laboratory framework integrating topology optimization and laser powder bed fusion for engineering education," *Comput. Appl. Eng. Educ*., vol. 32, no. 3, e22745, 2024.

[13] M. A. Hazrat *et al*., "Developing a skilled workforce for future industry demand: The potential of digital twin-based teaching and learning practices in engineering education," *Sustainability*, vol. 15, no. 23, 16433, 2023.

[14] J. Knighton and R. Orr, "Integrating small team project-based learning in introductory manufacturing engineering technology: Design, manufacture, and race hot wheels-type cars," *Int. J. Eng. Sci. Technol*., vol. 6, no. 3, pp. 251–285, 2024.

[15] M. A. Rosyidi, A. W. Jufri, and I. P. Artayasa, "Development of biopreneurship project-based modul for junior high school students in

mandalika lombok special economic zone," *J. Res. Sci. Educ.*, vol. 9, no. 9, pp. 7579–7590, 2023.
[16] A. M. Abelenda, F. Aiouache, and D. Moreno-Mediavilla, "Adapted business model canvas template and primary market research for project-based learning on management of slurry," *Environ. Technol. Innov.*, vol. 30, 103106, 2023.
[17] C. Pacher *et al*., "Engineering education 5.0: A systematic literature review on competence-based education in the industrial engineering and management discipline," *Prod. Manuf. Res.*, vol. 12, no. 1, 2337224, 2024.
[18] S. Namasivayam, A. S. M. Al-Obaidi, and M. H. Fouladi, "A conceptual curriculum design approach for educating engineers of and for the future," I*ndones. J. Sci. Technol*., vol. 8, no. 3, pp. 381–396, 2023.
[19] T. J. Gunawan, J. Wang, and P. C. Liao, "Factors of project-based teaching that enhance learning interest: Evidence from construction contract management course," *Sustainability*, vol. 14, no. 22, 15314, 2022.
[20] M. T. Munir *et al*., "Revolutionising engineering pedagogy: The role of 3D printing in modern engineering education," *Innov. Educ. Teach. Int*., pp. 1–19, 2024.
[21] A. M. Nur *et al*., "The influence of the project-based learning integrated ethno-STEM of chemical equilibrium on the pancasila student profile mutual cooperation dimension," *Int. J. Act. Learn*., vol. 9, no. 1, pp. 30–39, 2024.
[22] Y. Tekmen-Araci, "Teaching creativity in engineering schools: A review of the literature," *Int. J. Eng. Educ*., vol. 40, pp. 126–143, 2024.
[23] O. H. Totuk, Ö. Selvi, and S. Akar, "Fused filament fabrication in CAD education: A closed-loop approach," Int. J. Mech. Eng. Educ., vol. 53, no. 1, pp. 167–188, 2025.
[24] S. Sutopo *et al*., "Peer-project-based learning in CNC simulation programming courses," *TEM J.*, vol. 13, no. 4, 2024.
[25] I. D. Sol *et al*., "Complementary training for engineering students in additive manufacturing (3D printing)," in *Proc. INTED2023*, 2023, pp. 8776–8784.
[26] Y. Li, "Exploration of moral education in the teaching of mechanical design fundamentals," *Int. J. New Dev. Educ*., vol. 6, no. 5, 2024.
[27] S. B. Layeb, A. Jaoua, and M. Noomen, "New horizons in engineering education: From additive manufacturing to immersive learning," in *Proc. Adv. Addit. Manuf. Conf.*, 2023, pp. 87–91.
[28] E. Novak *et al*., "A systematic review of empirical research on learning with 3D printing technology," *J. Comput. Assist. Learn*., vol. 37, no. 5, pp. 1455–1478, 2021.
[29] V. Dolgopolovas and V. Dagiene, "Competency-based TPACK approaches to computational thinking and integrated STEM: A conceptual exploration," *Comput. Appl. Eng. Educ*., vol. 32, no. 6, e22788, 2024.
[30] M. A. Al-Gerafi *et al.*, "Promoting inclusivity in education amid the post-COVID-19 challenges: An interval-valued fuzzy model for pedagogy method selection," *Int. J. Manag. Educ.*, vol. 22, no. 3, 101018, 2024.
[31] N. Derevyanko and O. Zalevska, "Methods of introducing additive technologies into the educational process in the training of future graphic designers," *Sci. Bull. Mukachevo State Univ. Ser. "Pedagogy Psychol*., vol. 9, no. 1, pp. 69–79, 2023.
[32] J. Baranowski *et al*., "Creating future engineers: A case study of an interdisciplinary undergraduate course in technologies for Industry 4.0," in *Proc. 2023 IEEE 10th Int. Conf. e-Learn. Ind. Electron. (ICELIE)*, 2023, pp. 1–6.
[33] K. Suhada *et al*., "The role of project based learning strategies in fiqih subjects," *Al-Hijr: J. Adulearn World*, vol. 3, no. 3, 2024.
[34] R. Valeeva and E. Valeeva, "Promoting creativity of engineering students in the foreign language classroom," in *Educating Engineers for Future Industrial Revolutions: Proc. 23rd Int. Conf. Interact. Collab. Learn. (ICL2020)*, vol. 2, pp. 191–198, 2021.
[35] D. Cuperman *et al*., "Focusing a technology teacher education course on collaborative cloud-based design with Onshape," *Int. Conf. Interact. Collab. Learn*., pp. 465–477, 2021.
[36] P. Prongpimai *et al*., "Developing training set for competency enhancement in basic electrical and electronics works for unskilled learners," in *Proc. 2022 7th Int. STEM Educ. Conf. (iSTEM-Ed)*, 2022, pp. 1–4.
[37] Y. Qian, S. Vaddiraju, and F. Khan, "Safety education 4.0–A critical review and a response to the process industry 4.0 need in chemical engineering curriculum," *Safety Sci*., vol. 161, 106069, 2023.
[38] S. Windyariani and S. Setiono, "Performance assessment creative thinking rubric in Science Technology Engineering and Mathematics (STEM) learning," *J. Innov. Sci. Educ*., vol. 13, no. 2, pp. 64–73, 2024.
[39] D. Li, K. D. Ortegas, and M. White, "Exploring the computational effects of advanced deep neural networks on logical and activity learning for enhanced thinking skills," *Systems*, vol. 11, no. 7, p. 319, 2023.
[40] S. Irshad *et al*., "Vygotsky's Zone of Proximal Development (ZPD): An evaluative tool for language learning and social development in early childhood education," *Multicult. Educ*., vol. 7, no. 6, pp. 234–242, 2021.
[41] R. M. Ryan and E. L. Deci, "Self-determination theory," *Encyclopedia of Quality of Life and Well-being Research*, pp. 6229–6235, 2024.
[42] S. An, T. Eck, and H. Yim, "Understanding consumers' acceptance intention to use mobile food delivery applications through an extended technology acceptance model," *Sustainability*, vol. 15, no. 1, p. 832, 2023.
[43] J. Cabero-Almenara *et al*., "Technology-enhanced learning in health sciences: Improving the motivation and performance of medical students with immersive reality," *Appl. Sci*., vol. 13, no. 14, p. 8420, 2023.
[44] M. A. R. Foss and Y. C. Liu, "Creating solutions through project-based and experimental learning: A case study of the Concept Center," *Int. J. Eng. Educ*., vol. 37, no. 6, pp. 1630–1642, 2021.
[45] C. Kefalis, C. Skordoulis, and A. Drigas, "The role of 3D printing in Science, Technology, Engineering, and Mathematics (STEM) education in general and special schools," *Int. J. Online Biomed. Eng*., vol. 20, no. 12, 2024.
[46] O. H. Totuk, Ö. Selvi, and S. Akar, "Fused filament fabrication in CAD education: A closed-loop approach," *Int. J. Mech. Eng. Educ*., vol. 53, no. 1, pp. 167–188, 2025.
[47] A. Ekmekci and D. M. Serrano, "The impact of teacher quality on student motivation, achievement, and persistence in science and mathematics," *Educ. Sci*., vol. 12, no. 10, p. 649, 2022.
[48] D. Olugbade, "Exploring the impact of learning technologies in teaching interaction design: A case study at First Technical University, Nigeria," J. Educ. Pract., vol. 14, no. 21, pp. 43–55, 2023.
[49] C. A. Eden, O. N. Chisom, and I. S. Adeniyi, "Harnessing technology integration in education: Strategies for enhancing learning outcomes and equity," *World J. Adv. Eng. Technol. Sci*., vol. 11, no. 2, pp. 001–008, 2024.
[50] E. A. Abedi, "Tensions between technology integration practices of teachers and ICT in education policy expectations: implications for change in teacher knowledge, beliefs and teaching practices," *J. Comput. Educ.*, vol. 11, no. 4, pp. 1215–1234, 2024.
[51] M. Maričić and Z. Lavicza, "Enhancing student engagement through emerging technology integration in STEAM learning environments," *Educ. Inf. Technol.*, pp. 1–29, 2024.
[52] N. Omarov *et al*., "Applying an augmented reality game-based learning environment in physical education classes to enhance sports motivation," *Retos: Nuevas Tendencias en Educación fiSica, Deporte y Recreación*, no. 60, pp. 269–278, 2024.
[53] K. A. Bartlett and J. D. Camba, "Toward a broader understanding of spatial ability in CAD education," *Comput.-Aided Des. Appl.*, vol. 24, no. 1, pp. 39–54, 2023.
[54] B. Kaldarova *et al*., "Applying game-based learning to a primary school class in computer science terminology learning," *Front. Educ.*, vol. 8, 1100275, 2023.
[55] A. Almeida, E. Assunção, and A. B. Lopez, "EU funded projects for qualification and standards requirements in additive manufacturing," *Springer Handbook of Additive Manufacturing*, pp. 857–866, 2023.
[56] E. Idrizi, "Exploring the role of explainable artificial intelligence (XAI) in adaptive learning systems," in *Proc. Cogn. Models Artif. Intell. Conf.*, pp. 100–105, 2024.
[57] D. May *et al*., "Between hands-on experiments and Cross Reality learning environments–contemporary educational approaches in instructional laboratories," *Eur. J. Eng. Educ.*, vol. 48, no. 5, pp. 783–801, 2023.
[58] I. Saralar-Aras and Y. C. Schoenberg, "Unveiling the synergistic nexus: AI-driven coding integration in mathematics education for enhanced computational thinking and problem-solving," *Math. Educ.*, vol. 63, no. 2, pp. 233–254, 2024.
[59] E. Tyflopoulos, C. Haskins, and M. Steinert, "Topology-optimization-based learning: A powerful teaching and learning framework under the prism of the cdio approach," *Educ. Sci.*, vol. 11, no. 7, p. 348, 2021.
[60] M. Chen, "Synergizing computer-aided design, commercial software, and cutting-edge technologies in an innovative nozzle test apparatus for an engineering laboratory course," *Computer Applications in Engineering Education*, 2024.