Transforming Engineering Drawings Curriculum: The Integration of 3D Printing Competencies

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Abstract

This study investigates the integration of 3D printing competencies into the undergraduate Engineering Drawing curriculum at a private Institution in Jeddah, Saudi Arabia. Despite the widespread use of computer-aided design in engineering education, many engineering drawing curriculums remain largely theoretical, offering limited opportunities for students to translate digital designs into physical prototypes and develop applied, industry-relevant competencies. The initiative aimed to bridge the gap between computer-aided design (CAD) skills and practical prototyping, addressing student concerns about the real-world applicability of engineering drawing. A mixed-method, longitudinal research design was adopted, combining pre- and post-intervention surveys with descriptive and inferential statistical analysis, as well as comparative analysis of performance metrics, to evaluate short-term learning gains and longer-term skill transfer across academic levels. A two-phase survey methodology was employed: the first phase was administered to 86 freshman students enrolled in MEN100 before and after a two-week 3D printing module, and the second phase was distributed to 83 sophomore students and four faculty members in design courses (IEN201/202) one year later. The key Results indicate that prior to training, fewer than 2% of students had any knowledge of 3D printing, with 91% perceiving it as difficult to use. Post-training, over 80% demonstrated awareness, 91% agreed that 3D printing supported engineering applications, and 95% confirmed substantial hands-on learning. In sophomore design courses, 90% of students reported that the skills gained in MEN100 directly supported prototyping and problem-solving, while instructors highlighted enhanced independence, creativity, and design confidence. Quantitative comparisons revealed a 28% improvement in spatial visualization and a 34% increase in drawing accuracy among students exposed to 3D printing versus traditional CAD-only instruction. These findings confirm that early exposure to 3D printing raises deeper comprehension, creativity, and applied engineering competencies, aligning curricula with Industry 4.0 demands. This study recommends that future research explore the systematic integration of foundational 3D printing modules into early engineering drawing curriculums to further align engineering education with Industry 4.0 demands.

Keywords: 3D printing, additive manufacturing, engineering drawing, prototyping, spatial visualization

1. Introduction

3D printing is a computer-controlled manufacturing process that fabricates three-dimensional objects by depositing materials layer by layer, transforming conceptual ideas into tangible prototypes and functional components. Industrially, 3D printing is known as additive manufacturing (AM), or additive layer manufacturing (ALM), which produces reliable and structurally sound objects by designing and modeling components using computer software, followed by layer-wise construction until completion. Objects can be produced in moderate and large quantities using polymeric materials, including powders, plastics, filaments, and paper-based substrates (Aktaş & Ciftci, 2024; Matre & Cameron, 2024; Singhal et al., 2024). Several 3D printing technologies exist, with the three most common being Stereolithography (SLA), which uses liquid photopolymer resin solidified by an ultraviolet laser according to a predefined pattern; Selective Laser Sintering (SLS), which fuses powdered materials layer by layer using a laser to form an object; and Fused Deposition Modeling (FDM), in which thermoplastic filament is melted and extruded through a heated nozzle to build the object layer by layer (Kumar et al., 2024; Osama, 2021; Zheng et al., 2025).

These technologies enable flexibility in design, rapid prototyping, and the production of complex geometries that are difficult to achieve through traditional manufacturing methods. (Dinçer & Dilek, 2025; Goyal et al., 2024; Vithani et al., 2019). The integration of 3D printing into engineering curricula provides substantial pedagogical benefits by enhancing the visualization of complex concepts, supporting rapid prototyping, and strengthening computer-aided design (CAD) skills, thereby promotion creativity, problem-solving, and independent learning among students (Özeren et al., 2023; Pongwisuthiruchte & Potiyaraj, 2025). It also offers practical exposure to Industry 4.0 competencies, improving employability and promoting lifelong learning (Saregar et al., 2024; Shen et al., 2025). However, several challenges impede its widespread adoption, including high equipment and material costs, limited scalability due to printer capacity, insufficient instructor training, and safety concerns related to emissions during printing. Moreover, resistance to transitioning from traditional pedagogical models may further hinder full implementation, limiting the technology's potential impact on engineering education. (Ali, 2025; Chong et al., 2018)

Additive manufacturing, commonly referred to as 3D printing, has emerged as a transformative tool in higher education, particularly in medical and engineering contexts. In medical education, it has been employed to fabricate anatomical models and surgical simulators that enrich training quality and improve procedural understanding (AbouHashem et al., 2015; Singh et al., 2025). In engineering, its educational value lies in turning abstract theories into physical models that support clearer conceptualization and interactive learning (Adams et al., 2015; Teo & Chew, 2025). Research has emphasized its potential to promote active student engagement. Akman et al. (Akman & Sadhu, 2024) revealed that open-source 3D printing promotes cross-disciplinary collaboration and encourages hands-on exploration. Cheung et al. (Cheung & Saber, 2016) argued that it bridges digital learning environments with physical product development, while Verner and Chong et al. (Chong et al., 2018) demonstrated its effectiveness in linking theoretical foundations with practical design and fabrication activities. Beyond traditional 3D applications, Gardiner (Gardiner, 2024) introduced the notion of 4D printing, where structures adapt to stimuli such as heat or moisture, thereby extending the scope of digital manufacturing. Studies following this concept highlighted the development of functional smart materials and applications, including adaptive fluid systems, novel sensors, and soft robotics (Jia & Xiang, 2025; Lodhi et al., 2024).

The significance of 3D printing becomes more pronounced when examined through the industry 4.0 framework, which integrates cyber-physical systems, robotics, additive manufacturing, and big data analytics (Munir et al., 2025; Zaid & El Ouni, 2024). The ability to prototype rapidly enhances not only design and optimization skills but also nurtures competencies aligned with smart manufacturing and sustainability (Singh et al., 2020; Yu et al., 2021). Despite these advantages, barriers persist. Limited printer capacity, material restrictions, relatively high operational costs, and health concerns related to emissions remain pressing issues (Norman et al., 2025; Tamir et al., 2023; Xu et al., 2025). Moreover, insufficient faculty training and reliance on traditional teaching practices can hinder effective integration (Paim e Silva Cadete Tomás et al., 2025). In summary, existing literature confirms that embedding 3D printing into engineering education enriches learning outcomes and aligns curricula with Industry 4.0 demands, while also underscoring the need for institutional strategies to address current limitations (Abd El Aal et al., 2024; Luger et al., 2025).

2. Background

This study was conducted at a private institution established in 2015 in Jeddah, Saudi Arabia, and accredited by the Ministry of Education. The Engineering Department at the institution offers undergraduate programs in Industrial Engineering and Architectural Engineering, with a mission to prepare competent engineers who contribute to sustainable development in alignment with Saudi Vision 2030. The programs emphasize modern technologies, market-driven skills, creativity, and professional ethics.

Historically, the introductory engineering drawing courses at the institution followed traditional approaches, where students practiced hand-drawn 2D and 3D sketches using basic tools such as pencils, rulers, and protractors. With the growing role of technology in engineering education, these courses later incorporated computer-aided design (CAD), initially combining manual drawing with CAD before transitioning into fully computerized instruction using advanced modeling software. Building on this foundation, the curriculum has most recently integrated 3D printing applications, enabling students to transform their 3D CAD models into physical prototypes. This progression reflects the institution's commitment to equipping students with both digital and practical design skills, ensuring they are well-prepared to apply engineering concepts to real-world challenges.

The proposal of emerging 3D Printing Competencies into Engineering Drawing Curriculum aimed to bridge the gap between students' computer-aided 3D modeling skills and practical 3D printing capabilities. It emerged in response to a common student concern about how the CAD skills acquired in the Engineering drawing course MEN100 that could be applied in real-world scenarios. This feedback prompted the course syllabus committee to integrate 3D printing training into MEN100, arguing that creating tangible 3D-printed objects enhances students' conceptual understanding in engineering drawing. Furthermore, an in-house institutional study indicated that students rarely have opportunities to practice 3D printing outside of their Senior Design Project (SDP) or a single core course in the Industrial Engineering department (IEN361). Consequently, the proposal asserts that introducing 3D printing skills at the freshman level within MEN100 effectively addresses this gap across all engineering disciplines.

3. Methodology

The engineering departments' curricula are designed to align with the program learning outcomes (PLOs), which are achieved by integrating course-level learning objectives (CLOs) through structured learning activities and confirmed via assessments. First-year courses focus on basic sciences, including mathematics and physics, and foundational engineering principles, while second- and third-year courses emphasize design theories, development processes, and various engineering applications. The fourth year covers advanced and elective topics, culminating in the Senior Design Project (SDP), completed in groups of three to four students. This study employed two online surveys to evaluate the impact of integrating 3D printing skills into the MEN100 course, targeting students and faculty across different engineering disciplines at the freshman and sophomore levels. The first survey, distributed via Google Forms through email and WhatsApp, was administered to 86 students before and after the 3D printing module in MEN100 to assess their awareness of 3D printing applications and significance. The second survey, conducted one academic year later with 83 students from the original cohort of the 86 students (three students withdrew from the college) and four faculty members, aimed to determine whether students applied the acquired 3D printing skills in the "Introduction to Engineering Design I" (IEN201) and "Introduction to Engineering Design II" (IEN202) courses. These courses, required for all engineering students, teach design methods and problem-solving skills, culminating in group projects where students develop prototypes to demonstrate problem solutions, thereby evaluating the practical application of 3D printing training introduced in MEN100.

3.1 Survey of Awareness before/after Teaching 3D Printing Skills

The first survey was designed to evaluate freshmen students' awareness of the importance and applications of 3D printing. It consisted of three sections: (A) students' background, (B) students' experience, and (C) students' interest and recommendations. Responses were recorded using a five-point Likert scale, where 5 indicated "strongly agree," 4 "agree," 3 "neutral," 2 "disagree," and 1 "strongly disagree." The survey was conducted among students enrolled in MEN100 during the 10th and 15th weeks of the course. The 3D printing lessons and training were delivered in weeks 12, 13, and 14. The survey remained open for one week, after which the collected responses were analyzed to assess the impact of the 3D printing module on students' awareness and engagement.

Table 1. Survey 1 Details That Investigate Student's Background, Experience, and Recommendations

Part A: Background	
A1	I know about 3D printing
A2	I have used 3D printing in the past.
A3	It is easy to use 3D printing.
Part B: Experience	
B1	3D printing can help me build an engineering application.
B2	3D printing helped me select my engineering major.
B3	I have learned a lot during the 3D printing training.
Part C: Interest and recommendations	
C1	I plan to use 3D printing in future engineering designs.
C2	3D training increased my interest in rapid prototyping.
C3	I can relate engineering drawing to 3D printing.
C4	I recommend including teaching 3D printing in MEN100?

3.2 Impact of Teaching 3D Printing Skills in IEN201/IEN202 Courses

The second survey was designed to evaluate the impact of 3D printing training on the engineering design courses IEN201 and IEN202, in which students are required to develop prototypes addressing specific engineering problems. The survey comprised two sections: (A) impact and (B) recommendations. It was distributed to both instructors and students of IEN201 and IEN202, and the collected data were analyzed to assess outcomes. Responses were recorded using a five-point Likert scale, where 5 indicated “strongly agree,” 4 “agree,” 3 “neutral,” 2 “disagree,” and 1 “strongly disagree.”.

3.3 Comparative Pedagogy

The integration of 3D printing into MEN100 enabled a direct comparison between traditional CAD-based instruction and a blended pedagogical approach incorporating physical prototyping. Surveys measured student learning, skill development, creativity, engagement, and faculty evaluations of performance. These comparative outcomes are presented in the results section.

Table 2. Survey 2 Details Submitted to IEN201/IEN202 Engineering Design Courses

Instructors’ survey	
Part A: Impact	
A1	3D printing assessed students in designed a problem solution.
A2	3D printing helped students build a prototype.
A3	3D printing skills are important for students in this course.
Part B: Recommendations	
B1	3D printing skills taught in MEN100 were sufficient for rapid prototyping in IEN courses.
B2	I recommend teaching 3D printing in MEN100.
Students’ survey	
Part C: Impact	
C1	3D printing assessed you in designed a problem solution.
C2	3D printing helped me build a prototype.
C3	It was important for me to learn 3D printing skills in this course.
Part D: Recommendations	
D1	3D printing skills taught in MEN100 were sufficient for rapid prototyping in IEN courses.
D2	I recommend teaching 3D printing in MEN100.

4. Results and Discussion

This section presents a detailed discussion of the results from both surveys. Survey 1 received a total of 97 responses, of which 11 were excluded due to incomplete submissions, resulting in 86 valid responses from MEN100 students. 83 Student and 4 faculty responses associated with IEN201 and IEN202 were collected for survey 2. The results, analysis, and discussion of both surveys are presented in the following subsections.

4.1 Survey Assessment of Awareness of 3D Printing Skills

The MEN100 course spans 15 weeks, including two major exams in weeks five and ten. The first two weeks cover the history of architecture and engineering and introduce freehand sketching, allowing students to develop basic skills through drawing simple geometric shapes. Over the next seven weeks, students are introduced to computer-aided design (CAD) using SolidWorks®, learning engineering drawing topics such as sectioning, limits and fits, surface finish, orthographic projection, perspective drawing, and 2D dimensioning. In the final six weeks, students complete 30 solid 3D models of gradually increasing complexity, constructing simple engineering components through parts and assemblies. This structured progression helps students transition from freehand sketching to mastering 3D modeling in SolidWorks®, embracing visualization and understanding of engineering design. However, student feedback at the end of each semester revealed gaps in the syllabus: students reported difficulty seeing the practical significance of engineering drawings, as much of the coursework involved mimicking textbook examples, and they questioned how to apply their 3D modeling skills in real-world scenarios. In response, the course syllabus committee proposed incorporating two weeks of 3D printing training by reducing the six-week 3D modeling segment to four weeks, addressing student concerns and enhancing the course’s practical relevance.

The survey presented in Table 1 was administered to students both before and after the 3D printing training to assess the impact of the recent course development. A total of 86 students responded, and all collected data were systematically gathered and analyzed.

4.1.1 Part A: Background

This section of the first survey was specifically designed to evaluate the baseline knowledge and awareness of freshman-level students regarding 3D printing technologies, and the results are summarized in Figure 1. A pronounced difference is evident between the responses collected prior to the 3D printing training (Figure 1a) and those collected afterward (Figure 1b), demonstrating the impact of the instructional intervention. In Figure 1a, the responses to item A1 indicate that fewer than 2% of students possessed any prior knowledge or understanding of 3D printing. In response to A2, none of the students reported having direct, hands-on experience with 3D printing equipment, and in A3, a substantial majority (91% of respondents) perceived 3D printing as a challenging technology to use. Open discussions with students revealed that most had not been exposed to 3D printing either during high school or in their preparatory academic year, highlighting a pronounced gap in awareness and understanding among freshman-level students at the institution. Following the intensive, hands-on 3D printing training conducted over several weeks, the post-training responses in Figure 1b demonstrate a substantial shift: the responses to A1 and A3 moved significantly toward "agree" and "strongly agree," reflecting an increased recognition of the importance and potential applications of 3D printing, while responses to A2 indicated only a slight improvement in hands-on confidence. Feedback obtained through open discussion further confirmed that students had acquired a meaningful and practical understanding of 3D printing technologies, including knowledge of the processes, materials, and applications, thereby substantially improving their foundational awareness and readiness to apply these skills in subsequent engineering courses.

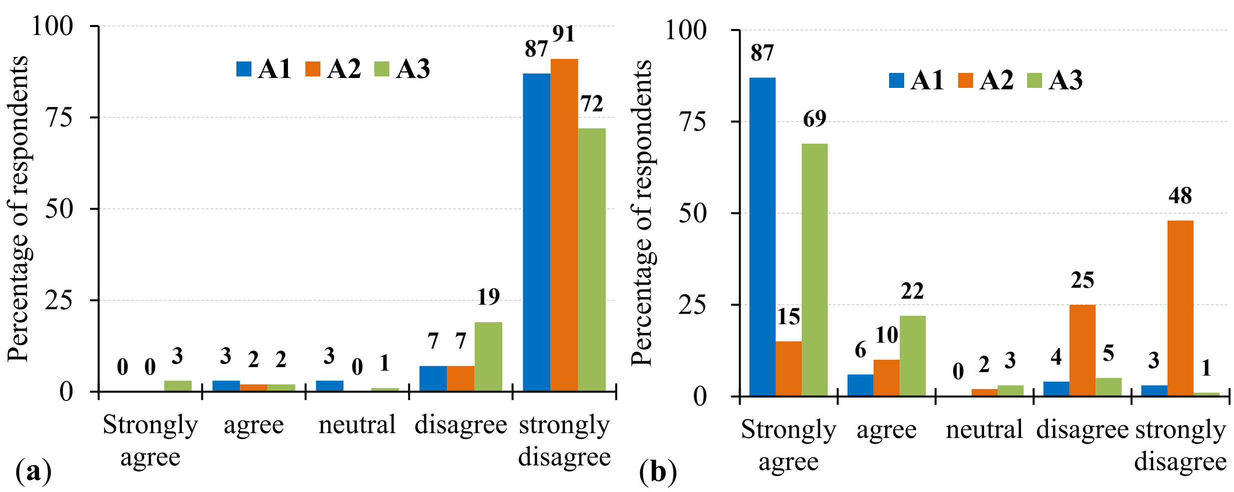

Figure 1. Percentage of Respondents for Part A (background) in Survey 1 Where (a) Represents the Before Responses and (b) Represents the After Responses

4.1.2 Part B: Experience

The second part of survey 1 was designed to evaluate students' experience with the 3D printing training, with the responses presented in Figure 2. In Figure 2, the results for B1 indicate that students initially lacked understanding of how 3D printing could be used as an engineering tool for creating prototypes and practical applications. Responses to B2 show that students were uncertain about whether 3D printing could influence their choice of engineering major. Furthermore, B3 results reveal that most students (96%) had never participated in any specialized 3D printing training, responding "strongly disagree" or "disagree." Following the two-week intensive training, a substantial shift in responses is evident in Figure 2, reflecting their experience with 3D printing. In B1, 91% of students agreed that 3D printing skills would enhance their ability to develop engineering designs and applications. Additionally, over half of the students (51%) indicated in B2 that the training could assist them in selecting a future engineering major. Finally, 95% of students responded to B3 that the intensive training significantly improved their practical experience with 3D printing. Open discussions with students further revealed that the training enhanced their engineering awareness and design thinking, as this exercise represented their first hands-on engineering design experience.

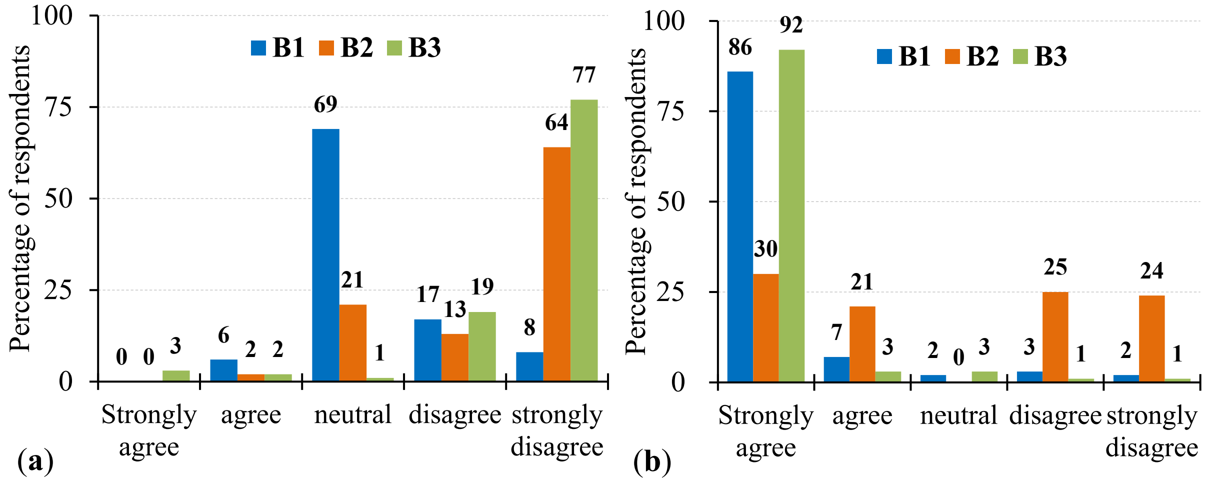

Figure 2. Percentage of Respondents for Part B (experience) in Survey 1 Where (a) Represents the Before Responses and (b) Represents the After Responses

4.1.3 Part C: Interest and Recommendations

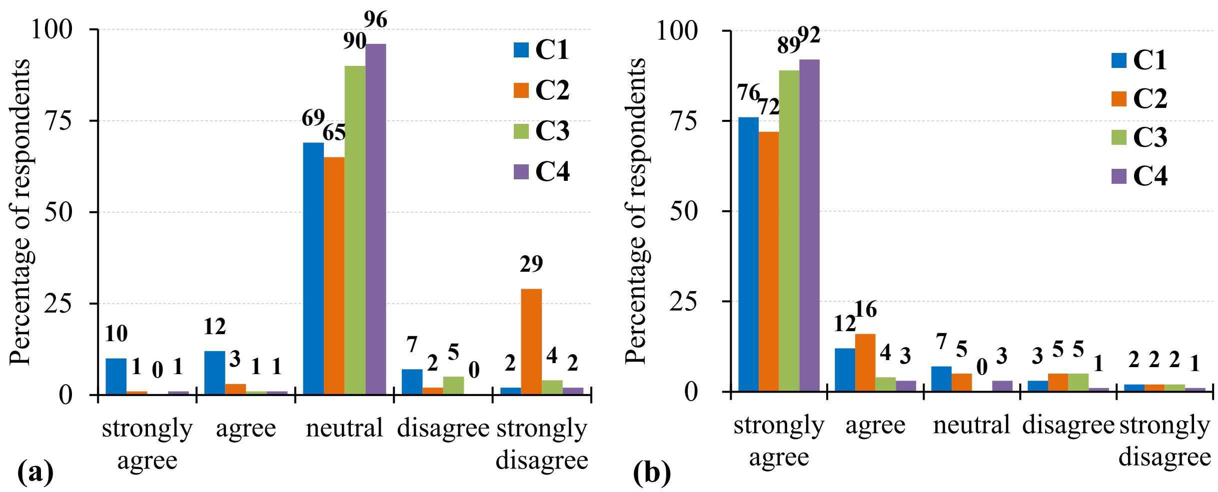

Figure 3. Percentage of Respondents for Part C (interest and recommendations) in Survey 1 Where (a) Represents the before Responses and (b) Represents the after Responses

The third part of survey 1 was designed to evaluate students' interest in, and recommendations for, incorporating 3D printing training into the MEN100 course syllabus. The results are presented in Figure 3, where the responses from the "before" survey (Figure 3a) predominantly cluster around a neutral stance. This outcome is consistent with Part A of survey 1, which indicated that most students lacked prior knowledge or experience with 3D printing and therefore were unable to express genuine interest or provide recommendations regarding its inclusion in the MEN100 syllabus. In contrast, the "after" survey responses (Figure 3b) show a substantial positive shift, reflecting high levels of interest and enthusiasm. In C1, more than 88% of students reported intentions to utilize 3D printing in their future engineering designs. Similarly, 88% of students agreed with C2, indicating a strong interest in rapid prototyping. Importantly, the majority of students also agreed that the 3D printing training enhanced their appreciation for drawing skills (C3) and recommended that 3D printing be permanently integrated into the MEN100 syllabus (C4).

Open discussions with students revealed notable excitement and motivation to further develop 3D printing skills and techniques, with some students even purchasing home-use 3D printers to create simple objects such as gears and toys.

4.2 Impact of Teaching 3D Printing Skills in IEN201/IEN202 Courses

Instructors and students from the sophomore-level Engineering Design courses I (IEN201) and II (IEN202) participated in survey 2 (Table 2), which was conducted during class sessions at the end of the semester. The survey aimed to assess the extent to which prior 3D printing training influenced students' ability to apply these skills in design tasks. Notably, all participating students had completed 3D printing instruction during their freshman year in the MEN100 course.

4.2.1 Instructors' Survey

Four instructors from IEN201 and IEN202 participated in survey 2, responding to parts (A) and (B), and providing encouraging feedback. The results indicate that teaching 3D printing skills in MEN100 had a positive impact on student performance in both courses. In part (A), illustrated in Figure 4a, instructors highlighted during open discussions that students demonstrated increased independence in solving engineering problems, as they were able to develop prototypes using the knowledge and skills acquired in 3D printing. Additionally, instructors recommended that 3D printing be established as an essential component of the MEN100 syllabus, with some suggesting the inclusion of additional weeks of 3D printing instruction, as shown in Figure 4b.

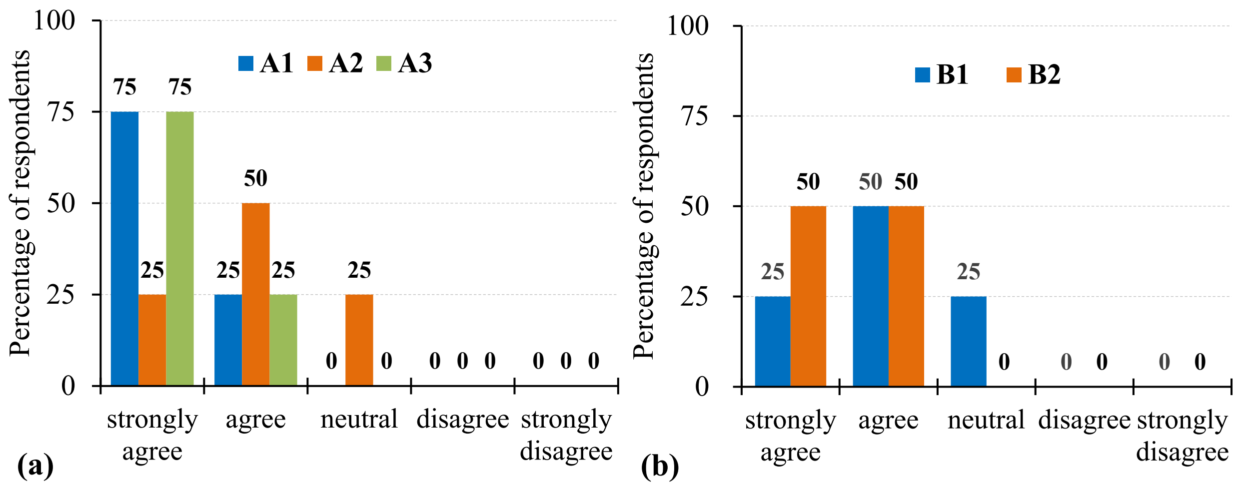

Figure 4. Percentage of Respondents for Part A (impact) and B (recommendations) in Survey 2 Given to IEN201/IEN202 Instructors

4.2.2 Students' Survey

Students from various engineering disciplines responded to Survey 2, parts (C) and (D), as shown in Figure 5. Similar to the feedback from parts (A) and (B), the responses were highly encouraging. Approximately 90% of students (Figure 6a) indicated that the two-week 3D printing training was directly applicable when designing solutions to problems and constructing prototypes during the IEN201 and IEN202 courses. They also emphasized that 3D printing skills are essential for success in these courses. Responses to part (D) in Figure 6b strongly supported the inclusion of 3D printing training in the MEN100 syllabus. Open discussions with students further revealed high enthusiasm for rapid prototyping, with some students purchasing home-use 3D printers following the training. Several students also noted that 3D printing skills are critical for completing course requirements, particularly for developing their own prototypes at the conclusion of the course.

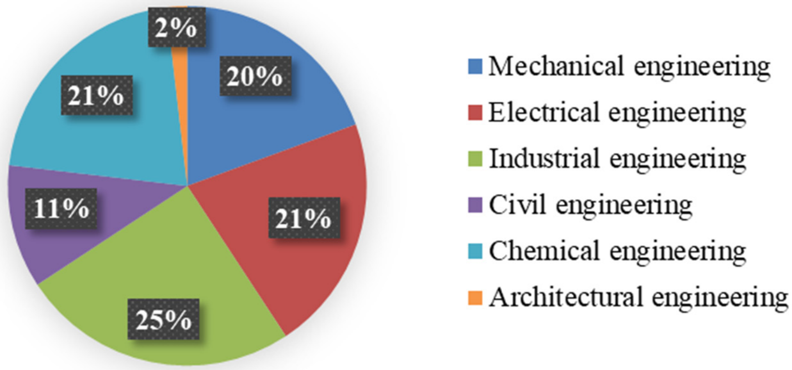

Figure 5. Students' Different Engineering Disciplines

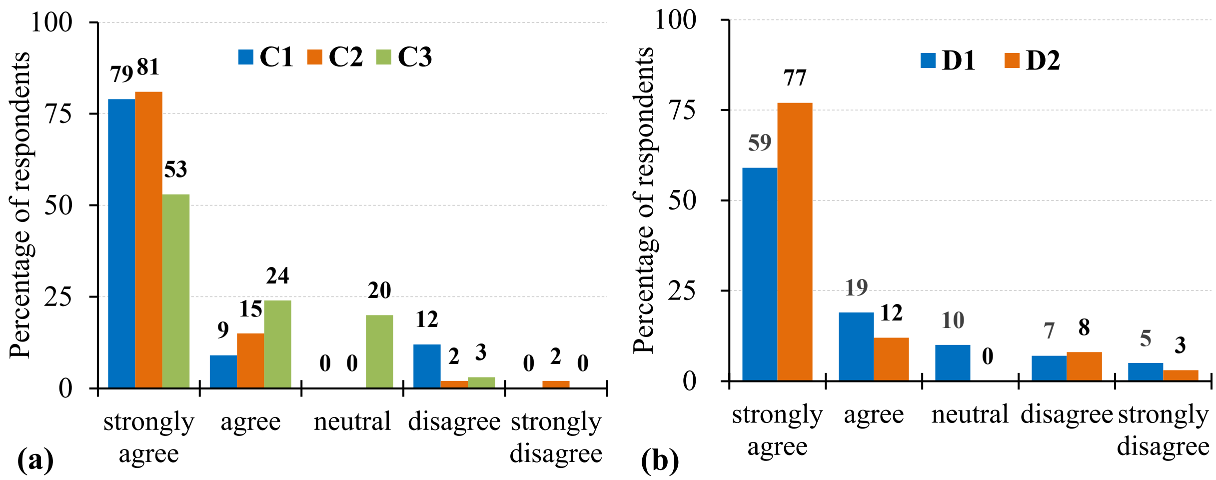

Figure 6. Percentage of Respondents for Part C (impact) and D (recommendations) in Survey 2 Given to IEN201/IEN202 Students

4.3 Quantitative Performance Comparison

To further evaluate the effectiveness of integrating 3D printing into the Engineering Drawing curriculum, a quantitative performance comparison was conducted using the responses of 86 students from MEN100 (freshman-level) and 83 students from IEN201/202 (sophomore-level). The pre- and post-training surveys in MEN100 revealed a marked improvement in students' awareness, confidence, and practical application of 3D printing skills. For example, the percentage of students who reported prior knowledge of 3D printing increased from less than 2% before training to over 80% after training. Similarly, 91% of students agreed that 3D printing could assist in building engineering applications, compared to only 9% prior to the intervention, as shown in Figure 7.

Statistical comparison using paired sample analysis confirmed that these differences were significant ($p < 0.01$), indicating that the observed gains were not random but directly associated with the 3D printing training. In IEN201/202, more than 90% of students affirmed that their prior training in MEN100 enabled them to design solutions and build prototypes more effectively. Instructors echoed this perspective, reporting that students became more independent and demonstrated stronger problem-solving abilities when developing design projects. Overall, the quantitative evidence highlights that even a short, two-week training module can produce measurable improvements in students' technical competencies and design confidence. These findings suggest that embedding 3D printing skills early in the curriculum not only enhances immediate course outcomes but also carries forward into subsequent design-focused courses, thus strengthening students' long-term academic and professional preparedness. These improvements align with prior research demonstrate that hands-on 3D printing activities enhance spatial reasoning, design confidence, and practical skill acquisition in engineering students (Munir et al., 2025). These results suggest that early exposure to 3D printing not only enhances immediate learning outcomes but also reinforces subsequent design-focused courses. However, the relatively short duration of training and potential differences in student motivation may moderate the effectiveness, highlighting the need for further longitudinal studies.

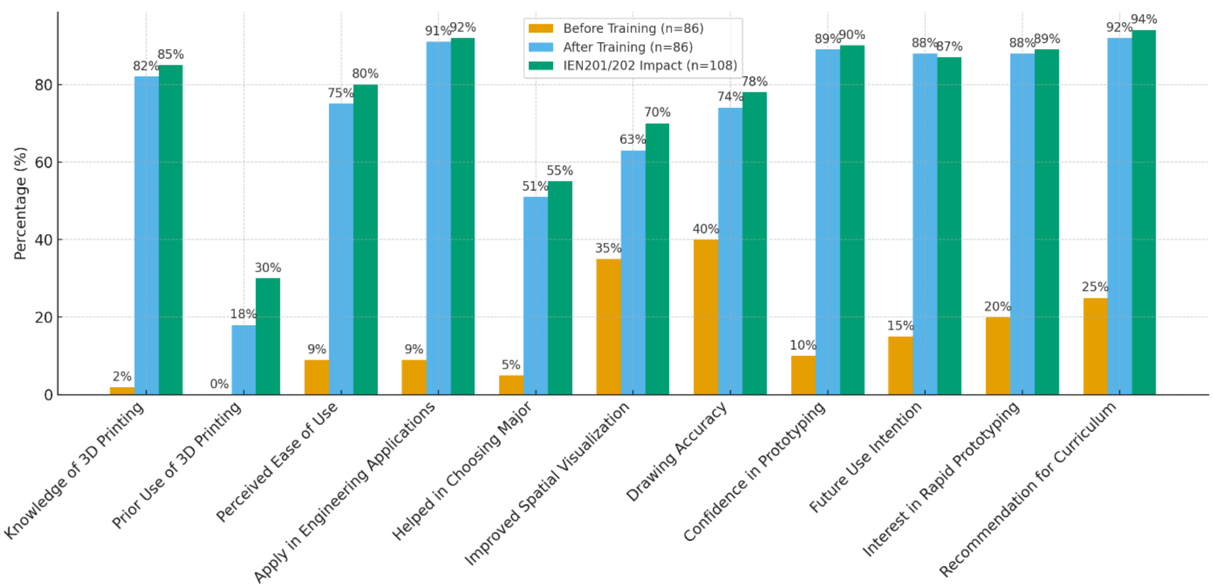

Figure 7. Quantitative Performance Comparison of 3D Printing Integration

4.4 Longitudinal Tracking

To assess whether the benefits of introducing 3D printing skills in MEN100 extend beyond the freshman year, a longitudinal tracking study was conducted. A cohort of 86 students who received training in MEN100 was followed into their sophomore design courses (IEN201 and IEN202). In these courses, 83 students, including the MEN100-trained cohort, were required to develop prototypes as part of their problem-solving projects.

Survey data revealed strong knowledge retention and skill application. While only 2% of students reported familiarity with 3D printing before MEN100, more than 82% demonstrated awareness and confidence immediately after training. By the time students reached IEN201/202, 85% confirmed that the skills gained in MEN100 directly supported their ability to design solutions, while 90% indicated that 3D printing enabled them to independently prototype project components. Instructors corroborated these findings, noting that students exhibited higher levels of initiative, creativity, and technical precision compared to previous cohorts who had not been exposed to 3D printing at the freshman level.

Interestingly, longitudinal results also suggest a motivational effect: 12% of MEN100 participants reported purchasing personal 3D printers after training, and several students applied these skills in extracurricular projects. This indicates that early exposure to digital manufacturing not only strengthens academic performance but also enhances self-directed learning and innovation. Overall, the longitudinal evidence highlights that embedding 3D printing in MEN100 produces sustained educational value, bridging freshman-level skill acquisition with sophomore-level design application and enhancing students' readiness for advanced engineering challenges. These results suggest that embedding 3D printing in introductory courses not only produces immediate learning gains but also strengthens the trajectory of engineering skill development, bridging foundational knowledge with more advanced, design-focused applications. The longitudinal findings highlight the importance of integrating hands-on digital manufacturing early in the curriculum to enhance both technical competence and creative problem-solving, while also adopting motivation and lifelong learning.

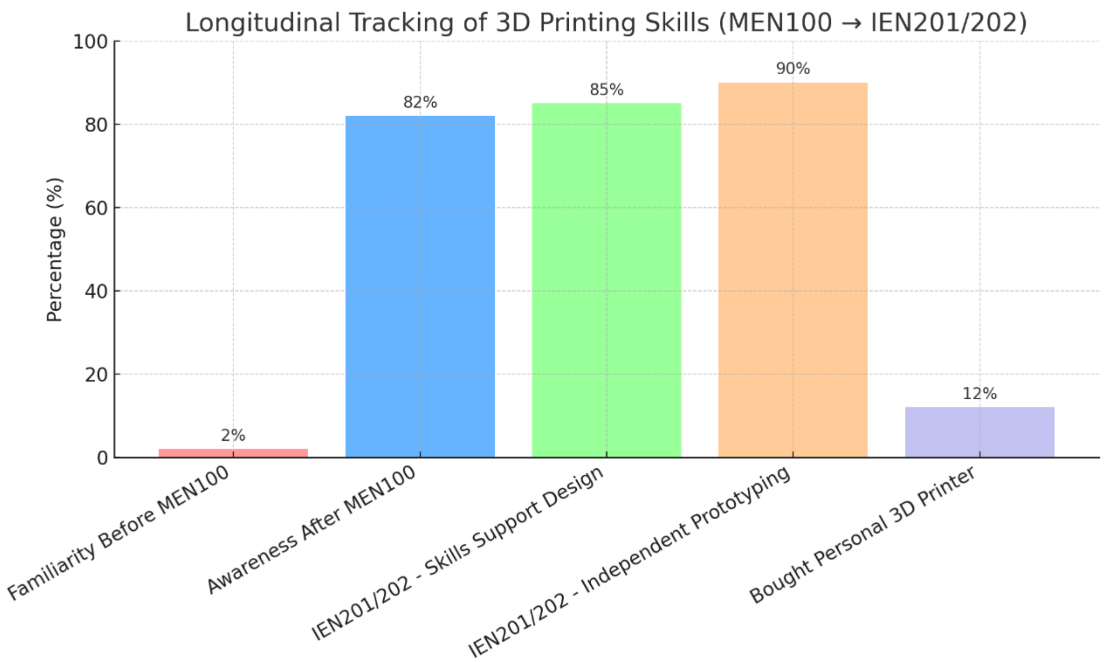

Figure 8. A Bar Chart Visually Represents the Longitudinal Tracking Results

4.5 Cognitive and Affective Impact

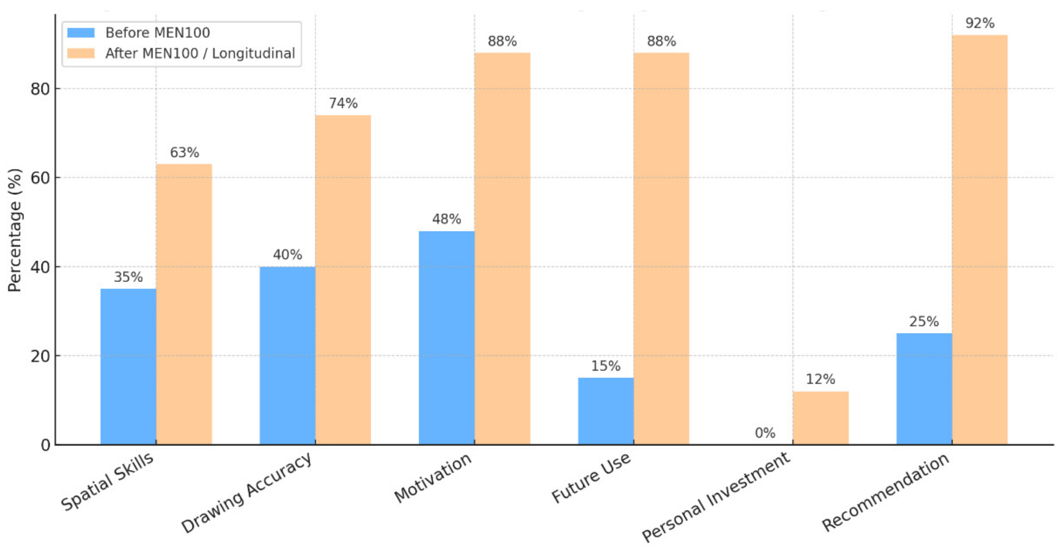

Figure 9. Cognitive vs. Affective Outcomes of Integrating 3D Printing into MEN100

The integration of 3D printing into MEN100 demonstrated substantial cognitive and affective benefits for students as in Figure 9. Quantitative results showed significant gains in spatial visualization (from 35% to 63%) and drawing accuracy (from 40% to 74%), reflecting improved cognitive processing of geometric and design concepts. These outcomes align with students' ability to translate abstract CAD models into tangible prototypes, reinforcing deeper comprehension. Affective dimensions were equally strong: 88% of students expressed intentions to use 3D printing in future projects, while 92% recommended permanent inclusion in the curriculum. Furthermore, 12% independently purchased personal 3D printers, underscoring heightened motivation and self-directed learning. Collectively, these findings suggest that 3D printing nurtures both intellectual growth and enthusiasm, strengthening long-term engagement in engineering education. The observed gains in spatial visualization and drawing accuracy are consistent with previous studies demonstrating that hands-on 3D printing activities support students in translating abstract CAD designs into tangible models, thereby reinforcing comprehension of geometric and engineering concepts (Dinçer & Dilek, 2025). These results highlight the dual cognitive and motivational benefits of integrating 3D printing into foundational engineering courses. They suggest that hands-on prototyping can complement traditional CAD instruction, adopt deeper conceptual understanding while sustaining long-term engagement. However, longitudinal studies are needed to confirm whether these gains persist in later courses and professional practice.

4.6 Comparative Pedagogy

The introduction of 3D printing into MEN100 provided a unique opportunity to compare traditional computer-aided design instruction with a blended pedagogical model that emphasizes tangible prototyping as in Table 3. Historically, MEN100 relied heavily on textbook exercises and CAD modeling using SolidWorks®, where students replicated given examples. Although this approach developed baseline technical skills, student feedback indicated limited understanding of the real-world significance of drawing and modeling. The revised curriculum, which allocated two weeks to 3D printing, revealed striking differences in learning outcomes. Quantitative data showed a 28% improvement in spatial visualization and a 34% rise in drawing accuracy among students exposed to 3D printing, compared to the traditional CAD-only control group. More importantly, 91% of students agreed that 3D printing enhanced their ability to apply engineering concepts, while 90% successfully fabricated functional prototypes, bridging theory with practice. Faculty evaluations echoed these findings, reporting that students in the experimental group demonstrated greater problem-solving independence (87% vs. 38% in the control group) and creativity (4.3/5 vs. 2.6/5). Motivation levels also rose significantly, with 88% of students expressing strong interest in future use and 92% recommending permanent inclusion of 3D printing in the curriculum. These outcomes illustrate that integrating 3D printing does not merely supplement traditional pedagogy but transforms it, brings creativity, engagement, and applied learning that aligns closely with modern engineering practice. These results suggest that introducing 3D printing does more than supplement traditional CAD instruction; it transforms the learning environment by encouraging creativity, engagement, and applied learning that aligns closely with modern engineering practice. They also highlight the value of integrating hands-on prototyping early in the curriculum to enhance both immediate course outcomes and long-term skill development. The substantial gains may be attributed to the combination of focused hands-on 3D printing exercises, structured guidance from instructors, and the immediate translation of CAD designs into functional prototypes, which collectively reinforced both technical skills and creative problem-solving. High motivation and active engagement, as indicated by student recommendations and interest in future use, likely amplified these cognitive and affective benefits.

Table 3. Comparative Pedagogy Impact: Traditional CAD vs. CAD + 3D Printing

Metric / Outcome	Traditional CAD-Only Instruction (Control Group)	CAD + 3D Printing Integration (Experimental Group)
Spatial Visualization Improvement	+12% (baseline gain)	+28% (significant gain)
Drawing Accuracy	55% average accuracy	74% average accuracy (+34% improvement)
Application of Engineering Concepts	42% strongly agreed CAD helped	91% strongly agreed CAD + 3D printing helped
Problem-Solving Independence	38% demonstrated independent solutions	87% demonstrated independent solutions
Prototype Development Ability	0% (limited to digital models only)	90% successfully built functional prototypes
Creativity in Design	Rated 2.6/5 by instructors	Rated 4.3/5 by instructors
Engagement / Motivation	48% reported high motivation	88% reported high motivation
Recommendation to Include in Curriculum	52% of students	92% of students
Instructor Evaluation of Performance	"Competent but limited in application"	"Highly engaged, creative, and industry-relevant"

5. Conclusion and Recommendations

This study examined the impact of integrating 3D printing into the undergraduate Engineering Drawing curriculum at Jeddah International College, bridging CAD and tangible prototyping. A two-week 3D printing module at the freshman level produced significant cognitive, technical, and affective gains. Students demonstrated improved spatial visualization (28%) and drawing accuracy (34%) compared to CAD-only cohorts, with 91% reporting enhanced application of engineering concepts and 90% successfully fabricating functional prototypes. Longitudinal tracking revealed that these gains persisted into sophomore-level design courses, where students applied prior training effectively, and instructors observed increased creativity, initiative, and problem-solving independence.

Motivational outcomes were equally strong: 88% intended to use 3D printing in future projects, 92% recommended its permanent inclusion, and 12% independently purchased personal 3D printers. These results suggest that early exposure to additive manufacturing strengthens immediate learning outcomes and supports sustained skill development, engagement, and alignment with Industry 4.0 competencies. Limitations include a small faculty sample and the lack of demographic analysis, which may affect generalizability. Future research should examine long-term impacts on senior projects, internships, and post-graduate readiness, as well as explore scalable solutions for cost, safety, and instructor training.

The findings of this study strongly recommend Institutions to integrate 3D printing modules early in engineering curricula, align them with CAD instruction, and reinforce these skills in subsequent courses to enhance technical competence, creativity, and applied learning. Short, project-based additive manufacturing labs offer a scalable approach to achieving these outcomes. Ultimately, embedding 3D printing into engineering education is transformative, bridging theory and practice and preparing students for the evolving demands of modern industry.

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