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Advancing Engineering Drawing Education for Design and Manufacturing Through the Flipped Classroom Approach: Evidence from Saudi Female Engineering Students

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Abstract

The need for continuous improvement in higher education teaching has increased focus on active learning strategies, especially in STEM fields. Engineering Drawing, a core skill for engineering students, demands intensive practice of the concepts learned. Therefore, due to higher student participation and peer-to-peer discussions in traditional lecture-based classrooms compared to those in flipped classrooms, this study assesses the impact of implementing the flipped classroom approach in an introductory engineering drawing course for undergraduate female students at King Abdulaziz University. To evaluate the effectiveness of the flipped classroom, a mixed-methods approach was employed, including Likert-scale surveys, classroom observations, and an assessment of a course project. The survey questions were grouped into six main categories. Cronbach's alpha measured the survey's internal consistency, with scores from 0.636 to 0.858, indicating acceptable to good reliability for most themes. For the course project, student groups applied their drawing skills to convert CAD models into functional, 3D-printed physical models. Results showed strong agreement across all categories, with Collaboration & Interaction (M = 4.79/5) and Preparedness & Adaptability (M = 4.74/5) scoring the highest. The course project, for the first time, led to a successful university exhibition titled "Design and Manufacturing in 3D Printing," and demonstrated students' ability to combine theory with practical skills. Observations revealed increased student engagement, peer support, teamwork, and self-directed learning behaviors. Overall, these findings suggest that the flipped classroom approach can be an effective and scalable teaching method for technical subjects.

Keywords
Flipped classroom, Engineering Drawing, SolidWorks, 3D printing, Female Students

1. Introduction

The flipped classroom, an active learning pedagogy, has recently attracted greater attention from educational scholars. In contrast with a traditional lecture-based classroom, this model uses digital resources such as video recordings and soft copies of subject materials for out-of-class learning. At the same time, class time is devoted to active learning activities, including group discussions and problem-solving. This student-centered learning approach emphasizes students' learning responsibility, motivation, and engagement. It also employs Bloom's Taxonomy by assigning pre-class, lower-order tasks — such as remembering and understanding concepts — and higher-order tasks — such as problem-solving, brainstorming, and creating. Ample research has shown the positive implications of active learning for improving students' memory and motivation, which in turn lead to higher academic performance (Bransford, Brown, and Cocking 2000; Eison 2010; Prince 2014).

Increasing research has examined the impact of flipped classrooms across STEM disciplines. The application of the flipped classroom strategy in STEM fields has been extensively studied in the literature. Empirical studies and metaanalyses have shown that flipped classroom learning can lead to better academic performance due to increased engagement and deeper understanding of concepts compared to traditional teaching (Freeman et al. 2014; Alten et al., 2019; Bredow et al., 2021; Martín et al., 2020; Strelan et al., 2020). Similarly, flipped models encourage student engagement and improve learning outcomes, especially when combined with well-structured in-class activities (Bishop & Verleger, 2020). Another study's findings support the effectiveness of the flipped learning approach in enhancing students' achievement, attitudes toward learning, motivation, and self-evaluation (Mulhim, 2020). During COVID-19, adaptive learning in online flipped classrooms improved perceptions of the online learning environment, increased preference for flipped instruction, and boosted motivation for independent learning. However, improvements in exam scores were only modest (Clark et al., 2021). By reviewing materials before class, students are better prepared to participate in discussions, ask questions, and solve challenging problems (Peisachovich et al., 2016). The in-class activities, often designed to be interactive and collaborative, further boost student interest and motivation. Additionally, the flipped classroom model allows instructors to provide personalized feedback and support, addressing individual learning needs and fostering a more profound understanding (Brame, 2016).

However, the literature also highlights potential challenges and limitations of the flipped classroom approach. A common concern is the extra time and effort required from instructors to create high-quality video lectures and facilitate in-class activities (Akçayır & Akçayır, 2018). Careful attention should be paid to factors such as video length, instructional design, and alignment with learning objectives to improve their effectiveness. The success of flipped classrooms relies on various elements, including the quality of pre-class materials, the design of in-class activities, and students' readiness for independent learning. In STEM fields, where abstract reasoning and procedural knowledge are crucial, flipped learning is effective when the transition from passive to active engagement is supported by thoughtful instructional design and effective scaffolding.

While the flipped classroom model has been extensively studied in Western educational settings, research on its effectiveness in Saudi Arabia, especially in engineering education for female students, remains limited. Recently, flipped learning has gained more attention in Saudi higher education, primarily as universities aim to align with Saudi Vision 2030, which highlights educational innovation, digital transformation, and student-centered learning. However, the distinct cultural and pedagogical context of Saudi Arabia requires careful adaptation and assessment of the flipped classroom model. Several studies have examined the implementation of flipped classrooms in Saudi universities across various disciplines, generally reporting positive results, including better academic performance, increased classroom engagement, and higher student satisfaction (Al-Amri, 2022; Alghamdi & Al-Bargi, 2017; Najmi, 2020).

Adopting active learning methods is crucial in engineering education, where developing skills in visualization, spatial reasoning, and technical communication is vital. Among the essential competencies in early engineering programs, engineering drawing holds a special place. It serves as the universal language of engineering, enabling students to communicate complex ideas through standardized graphical representations such as orthographic projections, isometric views, and sectional drawings. Mastering these skills lays the groundwork for more advanced tasks in design, modeling, analysis, and manufacturing across all engineering disciplines.

However, engineering drawing is often taught using traditional methods that depend heavily on demonstrations and repetitive practice. These approaches may not fully engage today's learners or utilize their ability for visual and hands-on learning. To address these issues, educators are increasingly trying flipped classroom strategies in engineering graphics courses. By moving content delivery to pre-class instructional videos and using class time for guided practice, group activities, and instructor feedback, the flipped model aims to improve student understanding while promoting independence and active participation. Although it is a fundamental part of engineering education, engineering drawing remains difficult for many students due to its reliance on spatial reasoning, abstract visualization, and mastery of technical standards. Traditional teaching methods—usually lecture-based and instructor-centered—often do not sufficiently engage students or accommodate different learning styles. As a result, many students find it hard to grasp core concepts, convert 2D representations into 3D mental images, or effectively apply drawing principles in design tasks. This ongoing gap highlights the need for more effective, student-focused teaching strategies that not only improve learning outcomes but also encourage deeper engagement, independence, and collaboration in engineering drawing courses.

This study explicitly examines the flipped classroom model as a promising teaching method for female engineering students in Saudi Arabia. The research is especially relevant given the ongoing national transformation under Saudi Vision 2030, which focuses on improving educational quality, empowering women, and integrating modern teaching technologies across all levels of education. As Saudi universities work to meet these goals, there is a significant need to assess innovative strategies that can support more inclusive, interactive, and outcome-oriented learning environments. Exploring the flipped classroom in this context offers valuable insights into how such methods can boost women's participation in engineering, enhance academic achievement, and align teaching practices with national development priorities. In the unique cultural and educational setting of Saudi Arabia, where gender-segregated education remains common in many institutions, implementing the flipped classroom model presents both opportunities and challenges. Understanding its effectiveness for female students in Saudi Arabia requires careful consideration of cultural factors, learning preferences, and the role of technology in fostering engagement and success. Therefore, this study investigates the effectiveness of the flipped classroom approach in teaching engineering drawing, emphasizing its impact on student engagement, preparedness, in-class experiences, and perceived learning outcomes. By providing empirical evidence on these aspects, this research aims to guide instructional design, support faculty development, and promote effective teaching practices in Saudi higher education, especially in female engineering programs.

Understanding how flipped learning impacts female students in technically demanding courses is essential for creating inclusive and effective teaching strategies. As more women enroll in engineering programs at Saudi universities, there is a pressing need for research that explores how active learning models, such as the flipped classroom, can be adapted to suit their learning preferences, boost confidence, and support their academic success in STEM fields. Research in STEM education has long emphasized the complex relationship between gender, learning experiences, and academic achievement, especially in technical subjects that involve spatial reasoning, abstract problem-solving, and practical application. (Dasgupta & Stout, 2014) Female students in engineering and other STEM disciplines often encounter challenges not because of their ability, but due to systemic and contextual factors like limited exposure to technical tasks, decreased self-efficacy, and underrepresentation in male-dominated fields. (Being Female in a (Still) (Male Engineering World, n.d.; Bystydzienski et al., 2015; O'Brien et al., 2014) Studies have demonstrated that teaching strategies that encourage active participation and collaborative learning, such as the flipped classroom model, can be especially effective in supporting female learners by offering structured guidance, regular feedback, and peer interaction in a low-pressure setting. (Alsmari, 2020; Parham, 2018). The success of this approach heavily relies on digital technologies, including video tools (Almisad, 2019).

In Saudi Arabia, cultural norms, gender segregation in education, and societal expectations have traditionally shaped women's access to and experiences in STEM fields. While recent reforms have led to significant progress in expanding educational and professional opportunities for Saudi women, barriers remain, especially in fields like engineering, where female participation is still relatively new. These cultural and social factors can influence how female students perceive their learning environment, interact with technology, and engage in collaborative activities. Therefore, it is crucial to consider these contextual elements when designing and assessing teaching strategies that support women in technical education. Exploring the impact of flipped learning in this context provides valuable insights into how inclusive, student-centered teaching methods can improve both academic performance and the learning experience for female engineering students. Although prior research has shown the benefits of flipped learning across various STEM disciplines, there is limited evidence of its effectiveness in hands-on, visually intensive courses such as engineering drawing. Additionally, existing studies in the Saudi context mostly focus on general education or theoretical subjects, with few addressing technical courses requiring advanced spatial and problem-solving skills. Even fewer examine gender-specific outcomes, despite the increasing number of Saudi women entering engineering programs. As Saudi Arabia continues to promote gender equality and educational reform, it is essential to investigate how flipped learning models can be tailored to support female students in technical fields.

This study aims to examine the effectiveness of the flipped classroom model in teaching engineering drawing to female engineering students in Saudi Arabia. Specifically, it seeks to:
1. Assess the effect of flipped learning on students' grasp of engineering drawing concepts and their overall academic performance.
2. Evaluate student engagement, motivation, and in-class experiences when using the flipped classroom model versus traditional lecture-based methods.
3. Investigate how the flipped classroom affects students' readiness, independence, and teamwork in a technical course environment.
4. Explore female students' perceptions of the flipped classroom method within the cultural and educational environment of Saudi Arabia.

5. Identify opportunities and challenges for expanding the flipped learning model within engineering education in line with Saudi Vision 2030.

2. Methodology

2.1. Flipped Classroom Model

The implementation of the flipped classroom strategy in this course was intentionally divided into three distinct phases, each designed to support student learning and steadily increase their independence and confidence in managing technical content. As a male instructor teaching female engineering students at a gender-segregated university in Saudi Arabia, I introduced this approach both as an instructional innovation and as a new experience for the students. (Alasmari, 2020; Al-Khalifa, 2010; Alsubaie & Jones, 2017) The flipped classroom model provides students the flexibility to review material at their own pace, which can be especially helpful for complex topics like engineering drawing (Almisad, 2019).

Phase One started with an orientation, where the professor explained the principles of the flipped classroom model and how it would be used in our course. Knowing that most students had never experienced this approach, I made sure expectations were clearly communicated. Lecture videos and foundational materials were shared at least four days before each session—usually over the weekend—to give ample time for pre-class study. (Jensen et al., 2015) These resources were accessible through our university's learning management system, which also included discussion forums where students could ask questions or discuss concepts with their peers. This early exposure was key to setting up a more interactive and productive in-class experience (Rotellar & Cain, 2016). During the next class, students were divided into small groups of two or three. This grouping helped students who struggled with the content get peer support and clarification. It also served as a good icebreaker, helping students, especially first-year engineering students who didn't know each other well, form social and academic connections that boosted their engagement and comfort in the classroom. (Joyce & Hopkins, 2011; Rodríguez-Simmonds et al., 2023)

In Phase Two, the group dynamics were modified in each session to involve different peers. This approach encouraged knowledge sharing and exposed students to various levels of understanding. Students were prompted to explain concepts to each other before moving on to individual practice. This phase balanced cooperative learning with fostering independence.

Phase Three marked the peak of the flipped learning model. By this point, students had become familiar with the format and expectations. Class sessions were designed as immediate problem-solving workshops: students entered the room, received new drawing assignments, and worked on them individually without prior instruction. This change aimed to build independence and mimic real-world application of their skills. With the structured, phased approach, students demonstrated notable gains in understanding concepts, collaborating with peers, and solving problems independently—results that align with the main objectives of flipped teaching, especially in skill-based technical fields like engineering drawing.

2.2. Research Design

This study used a quantitative research design to analyze the effect of the flipped classroom model on student learning outcomes, engagement, and classroom experiences in an engineering drawing course. A survey-based method was chosen to gather standardized data from a specific group of students, enabling statistical analysis of trends, perceptions, and experiences. The quantitative approach was suitable for measuring students' agreement with key learning areas (e.g., understanding, motivation, collaboration) and for assessing the effectiveness of a teaching method in a consistent, repeatable way. Although the study mainly emphasizes quantitative results, qualitative insights might be included in future phases to enhance understanding.

A structured questionnaire was created to evaluate students' perceptions of the flipped classroom model. The survey included 19 closed-ended questions, measured on a five-point Likert scale from "Strongly Disagree" (1) to "Strongly Agree" (5). The questions were developed based on the literature on flipped learning, STEM education, and student engagement, and organized into six thematic clusters.

- Learning Outcomes & Understanding
- Engagement & Motivation
- Preparedness & Adaptability
- Collaboration & Interaction

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• Practical Application & Problem-Solving
• Overall Preference & Satisfaction

The survey items within each cluster, as shown in Table 1, provide a thorough evaluation of the flipped classroom experience. This includes the clarity of instructional materials, the quality of in-class engagement, perceived learning improvements, and overall student satisfaction with the instructional approach.

Table 1. Survey questions classification based on thematic clusters

Cluster	**Survey Items**
Learning Outcomes & Understanding	1. The flipped classroom model helped me better understand the course material. 2. I felt more confident in my understanding of the course material through the flipped classroom than with traditional lectures. 3. The flipped classroom format led to better overall learning outcomes than traditional lecture-based teaching. 4. I believe that the flipped classroom model provides a more effective learning experience overall.
Engagement & Motivation	1. I felt more engaged in the flipped classroom compared to traditional lectures. 2. The flipped classroom model increased my participation in class discussions and activities. 3. Overall, the flipped classroom provided a more engaging and enriching learning experience than traditional lectures.
Preparedness & Adaptability	1. The pre-class videos/materials were clear and easy to follow. 2. The flipped classroom structure made me more prepared for in-class activities. 3. I found it easy to adapt to the flipped classroom model. 4. The flipped classroom model encouraged me to take more responsibility for my own learning.
Collaboration & Interaction	1. The interactive in-class sessions helped me reinforce the concepts learned in the pre-class materials. 2. The flipped classroom model improved my teamwork and collaboration skills. 3. The flipped classroom model was more effective in improving my in-class experiences compared to traditional lectures.
Practical Application & Problem Solving	1. Compared to traditional lectures, the flipped classroom model helped me better apply theoretical concepts in practical situations. 2. The flipped classroom model improved my problem-solving skills.
Overall Preference & Satisfaction	1. I preferred learning through the flipped classroom compared to traditional lectures. 2. I would prefer a flipped classroom approach over a traditional approach for future courses.

The participants in this study were female undergraduate engineering students enrolled in an engineering drawing course at King Abdulaziz University in Rabigh. The sample included only 43 female students, reflecting the research's gender-specific focus and aligning with the broader aim of examining educational outcomes for women in technical fields in Saudi Arabia. Data were gathered during the last two weeks of the semester. The Google Form survey was electronically distributed to all eligible students who participated in the flipped classroom. Students were informed about the purpose of the research and assured that their responses would remain confidential and would not affect their grades or course standing. Ethical considerations were carefully followed. Participation was completely voluntary and anonymous, with no identifying information such as names or student IDs collected or recorded.

Quantitative data were analyzed using descriptive statistics, including means and standard deviations for each item and cluster. Responses were numerically coded (1–5) on a Likert scale to facilitate statistical analysis. The analysis focused on identifying trends in student perceptions and measuring central tendencies within each thematic cluster. Additionally, cluster-level analysis was conducted to compare student perceptions across different dimensions of the flipped classroom experience. The internal consistency of survey clusters can be assessed using Cronbach's alpha to evaluate the instrument's reliability.

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While this study emphasizes quantitative results, the integration of a course project provided an opportunity to explore the effectiveness of the applied learning model. In addition to in-class activities, a final course project requiring the creation of 3D-printed objects was assigned. The students were asked to apply the engineering drawing skills they acquired throughout the course to develop a digital model, which was then fabricated using 3D printing. The project highlighted the integration of spatial reasoning, CAD modeling, and technical drawing standards, offering students a tangible outcome that demonstrated their ability to translate abstract visual information into functional, real-world products. It also served as a summative assessment of students' higher-order learning and application skills within the flipped classroom framework.

3. Results

The present study evaluated the survey instrument's reliability and examined students' perceptions of the flipped classroom model in an undergraduate engineering drawing course. Figure 1 summarizes the reliability analysis of the survey scales.

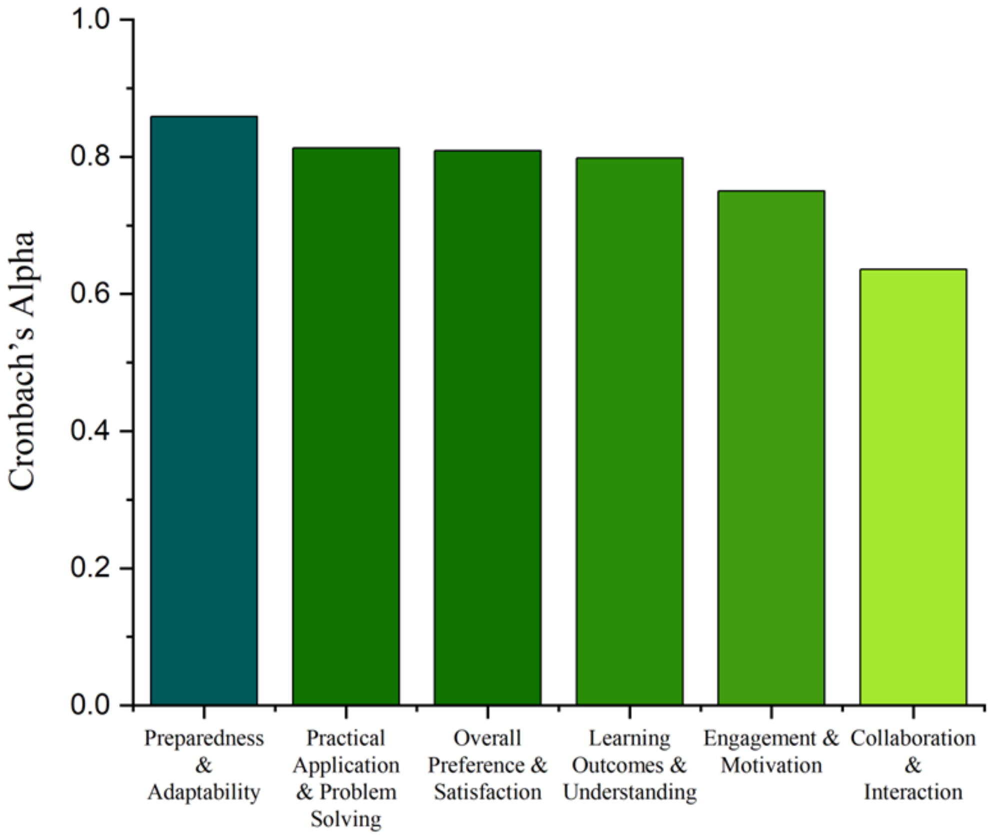

Figure 1. reliability analysis of the survey scales

Internal consistency of each thematic scale was assessed via Cronbach's alpha:
• Learning Outcomes & Understanding: α = 0.809
• Engagement & Motivation: α = 0.858
• Collaboration & Interaction: α = 0.813
• Practical Application & Problem Solving: α = 0.798
• Preparedness & Adaptability: α = 0.636
• Overall Preference & Satisfaction: (two-item scale; inter item r ≈ 0.75)

Alpha coefficients for four of the six scales exceed 0.80, indicating good reliability. These high alpha values suggest that the items grouped under these constructs consistently measure the intended dimensions. Students' responses were highly coherent when evaluating how well the flipped classroom supported their conceptual understanding, engagement levels, and in-class teamwork. One scale (Practical Application & Problem Solving) approaches the acceptable threshold, suggesting that the two items reliably capture students' perceived ability to transfer theory to practice. In contrast, the lower alpha for (Preparedness & Adaptability) falls below the conventional 0.70 benchmark. This variability could stem from differences in how materials were perceived or individual differences in self-directed learning readiness, suggesting opportunities for item refinement in future work. With only two items, traditional Cronbach's alpha is less stable. Instead, a high inter-item correlation ($r \approx 0.75$) suggests that both questions measure a similar sentiment regarding students' overall preference for the flipped format. Descriptive analysis of student responses (using a five-point Likert scale) revealed uniformly positive perceptions across all dimensions of the flipped model. The mean scores by cluster are listed below and are represented in Figure 2.

• Collaboration & Interaction: 4.79 (SD = 0.41)
• Preparedness & Adaptability: 4.74 (SD = 0.47)
• Engagement & Motivation: 4.72 (SD = 0.62)
• Learning Outcomes & Understanding: 4.71 (SD = 0.55)
• Overall Preference & Satisfaction: 4.60 (SD = 0.78)
• Practical Application & Problem Solving: 4.51 (SD = 0.84)

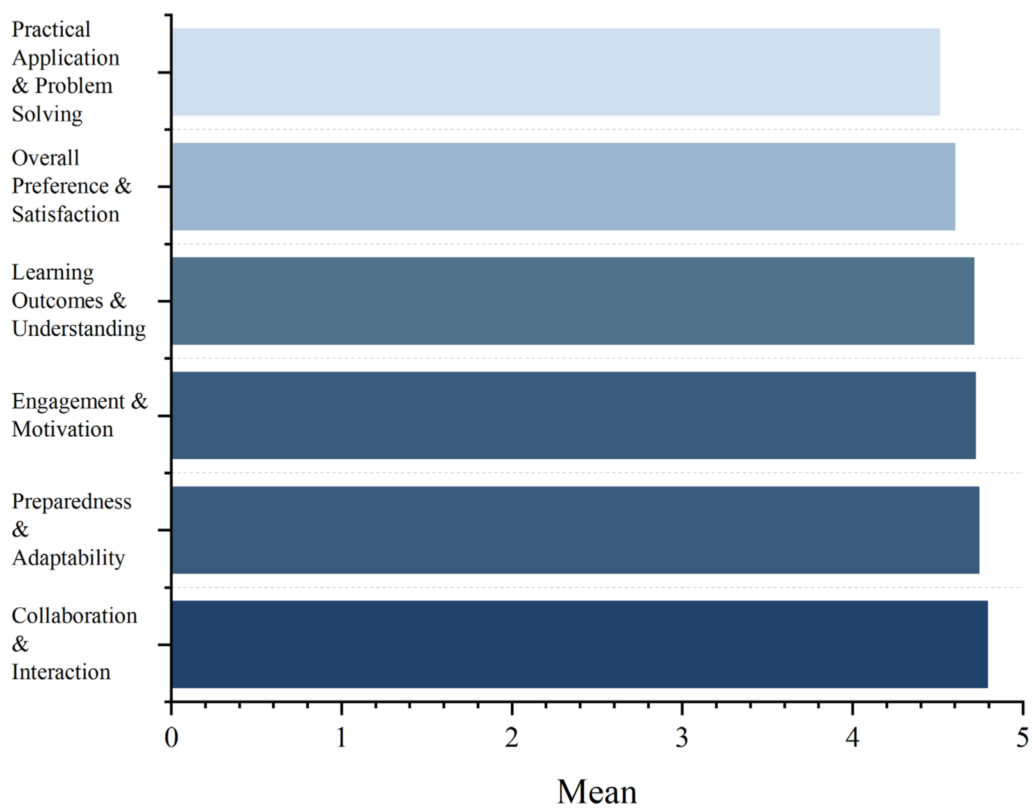

Figure 2. Students' Perceptions of the Flipped Classroom Model

The highest ratings for Collaboration & Interaction highlight the effectiveness of active, peer-led class sessions. Higher scores in Preparedness & Adaptability and Engagement & Motivation show that students found pre-class materials easy to understand and felt more engaged in their learning. Students largely agreed that the flipped classroom improved peer collaboration, prepared them well for active learning, boosted engagement, and enhanced their conceptual understanding. These findings match previous research indicating that active learning environments promote greater social and cognitive gains in STEM courses. Lower scores and more variation in Practical Application & Problem Solving and Overall Preference & Satisfaction suggest that some students might need additional support to improve their application skills and fully embrace the flipped format. Although generally positive, these areas showed more spread in responses. The wider range in problem-solving ability points to individual differences in students' perceptions of their skills. Similarly, a few students remained neutral or slightly less enthusiastic about the format, which might be influenced by personal preferences or prior experiences with flipped learning. High internal consistency and strong agreement on learning outcomes support the effectiveness of the flipped classroom for engineering drawing. The variation across specific scales indicates a need for better scaffolding, especially in problem-solving exercises, and possibly refining the survey. Future analysis of the 3D printing capstone project results will further demonstrate how well the model helps students develop advanced, applied skills.

The capstone project involved 43 students organized into 18 groups who collaboratively conceptualized, designed, and built the project. Students used SolidWorks to create 3D models, which were exported as STL files and processed with slicing software, resulting in over 250 G-code files. Fabrication was carried out using FDM-based 3D printers, producing 380 printed parts and totaling over 300 hours of print time. The projects had a variety of applications, including mechanical toys, kinetic mechanisms, functional tools, and artistic prototypes. Throughout this process, students demonstrated proficiency in digital modeling, slicing optimization, troubleshooting print errors, and applying effective post-processing and finishing techniques. This activity also promoted essential transferable skills such as teamwork, time management, and collaborative problem-solving. To ensure operational efficiency, a structured five-stage workflow was implemented: file submission, technical review, slicing preparation, printing, and post-processing. This initiative served not only as a practical extension of the engineering drawing curriculum but also aligned with Saudi Vision 2030 objectives, especially regarding youth empowerment, digital transformation in education, and fostering innovation and entrepreneurship. By linking theoretical knowledge with hands-on application, the project exemplified the flipped classroom model's ability to enable advanced, student-led design and manufacturing projects, while also highlighting its potential to strengthen university-industry collaboration within the Saudi context. Figure 3 shows the design and manufacturing in 3D printing exhibition where students present their projects.

Figure 3. Design & Manufacturing in 3D Printing

4. Conclusion
This study showed that using the flipped classroom model in an undergraduate engineering drawing course for Saudi female students significantly improved engagement, collaboration, and perceived learning outcomes. Survey analysis indicated consistently high ratings across six thematic areas, with the highest scores for Collaboration & Interaction and Preparedness & Adaptability. Cronbach's alpha values confirmed that most clusters had acceptable to good reliability, supporting the robustness of the measurement approach. Integrating design and manufacturing in the 3D Printing capstone project provided strong evidence of the model's ability to turn theoretical knowledge into practical, real-world skills. This research adds to the literature by exploring the often-overlooked connection between flipped learning, engineering drawing education, and gender-specific educational settings in Saudi Arabia. The results highlight the potential of the flipped classroom to promote active learning, enhance self-directed study habits, and foster more interactive, student-centered learning environments. Students reported feeling more prepared for class activities, more motivated to engage with peers, and more confident in applying engineering concepts. Additionally, this approach offers promise for advancing gender equity in STEM, as it creates a collaborative and supportive space that boosts both technical skills and confidence, especially in male-dominated fields.

Educators in Saudi Arabia and similar settings should consider adopting the flipped classroom approach for technical courses, especially those that require skill integration and hands-on application. To ensure effective implementation, they should include high-quality pre-class materials, well-organized in-class collaborative activities, and genuine project-based assessments, like the 3D printing project described in this document. Policymakers can further support these efforts by offering faculty training, providing technological resources, and creating industry-linked project opportunities to enhance university–industry collaboration and better prepare students for the workforce. Future research should use longitudinal designs to evaluate the long-term effects of flipped learning on skill retention, employability, and career readiness. Comparative studies across genders, disciplines, and types of institutions would also offer deeper insights into the model's adaptability and inclusiveness. Additionally, mixed-methods research that combines quantitative performance data with qualitative insights could shed more light on how flipped learning effectively supports diverse learners in technical and STEM education.

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Biography

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