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Making Online Asynchronous Class Effective and Successful: A Through Investion with Flipped Classroom Model

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Making Online Asynchronous Class Effective and Successful: A Thorough Investigation with Flipped Classroom Model

Abstract

With the growing demand for flexible and accessible education, online asynchronous courses have become an essential component of higher education, particularly for working and remote students. Although asynchronous delivery offers significant advantages in terms of flexibility and accessibility, traditional online courses often struggle to provide meaningful interaction, timely feedback, and sustained student engagement. Additionally, required synchronous components may create barriers for working learners due to fixed scheduling constraints. To address these challenges, this study examines the effectiveness of a flipped classroom model in a fully online, asynchronous course. The instructional design integrated pre-recorded video lectures for each module, optional weekly live discussion sessions, periodic quizzes, structured assignments, and two major examinations. Guided by a flipped instructional framework, the study investigated four research questions: (1) How does the flipped classroom model support student learning in a remote environment? (2) How convenient is the flipped model for students' engagement with course materials? (3) How does the flipped classroom model influence student motivation? and (4) What challenges do students encounter in online learning, and how does the flipped approach help mitigate these challenges? The study was conducted with twenty students enrolled in a fully online asynchronous STEM course. Pre- and post-surveys were administered to assess students' perceptions of learning efficiency, course content quality, instructional effectiveness, and multimedia quality. Quantitative analyses were used to examine changes across these dimensions following the flipped classroom implementation. The findings offer evidence-based insights into how flipped instructional strategies can enhance engagement, flexibility, and perceived learning effectiveness in online asynchronous learning environments.

1. Introduction

The rapid growth of online learning has significantly transformed higher education, offering increased flexibility and accessibility for diverse student populations, including working professionals, nontraditional learners, and geographically remote students [1], [2]. In particular, online asynchronous courses have gained prominence due to their ability to accommodate varied schedules and learning paces while reducing time and location constraints. Within engineering and STEM education, asynchronous delivery has become increasingly common as institutions seek scalable instructional solutions.

Despite these advantages, prior research has identified several challenges associated with asynchronous online learning. Students frequently report reduced engagement, limited interaction with instructors and peers, delayed feedback, and lower levels of motivation compared to face-to-face instruction [3], [4]. The lack of real-time interaction can be especially problematic in engineering and other STEM courses, where iterative explanation and immediate clarification are often necessary for conceptual understanding [5]. These factors may contribute to increased feelings of isolation and decreased persistence in online learning environments.

Synchronous online sessions are often incorporated to address these limitations; however, they introduce additional constraints for working and remote students. Fixed meeting times may conflict with professional or personal responsibilities, resulting in reduced participation and inconsistent attendance [6]. Additionally, once synchronous sessions conclude, students often lose access to instructor-guided explanations and real-time problem-solving opportunities, limiting opportunities for review and self-paced learning.

The flipped classroom model provides a promising instructional strategy to address these challenges in online asynchronous contexts. In this approach, instructional content is delivered through pre-recorded materials prior to interactive activities, allowing scheduled sessions to focus on discussion, application, and problem-solving [7]. Previous studies in engineering education have demonstrated that flipped instruction can promote active learning, increase student engagement, and improve learning outcomes [8], [9]. When implemented within an asynchronous course, the flipped model may offer increased flexibility while maintaining meaningful opportunities for interaction and feedback.

The purpose of this study is to examine the effectiveness of a flipped classroom model implemented in an online asynchronous course. Specifically, the study investigates students' perceptions of learning support, convenience, motivation, and challenges before and after the implementation of the flipped instructional design. The study is guided by the following research questions: (1) How does the flipped classroom support student learning in a remote environment? (2) How convenient is the flipped classroom model for students' engagement with course materials? (3) How does the flipped classroom model affect student motivation? and (4) What challenges do students face in online learning, and how does the flipped approach mitigate these challenges?

This study is significant for engineering and STEM education as it provides empirical evidence on effective instructional design strategies for fully asynchronous online courses. As online education continues to expand, identifying pedagogical models that enhance engagement, accessibility, and learning outcomes is essential for supporting student success in engineering and other STEM disciplines. Unlike many flipped classroom studies conducted in face-to-face or hybrid environments, this research examines a fully asynchronous implementation with minimal required synchronous participation. The course was specifically designed for working and remote students who may be unable to attend scheduled sessions, addressing a gap in the literature where flipped models typically rely on regular real-time interaction. By focusing on a fully asynchronous STEM course and using pre- and post-survey data to assess multiple dimensions of the learning experience, this study provides insight into how flipped instructional principles can be adapted to highly flexible online environments.

2. Prior Research on Asynchronous Learning and Flipped Classroom Models in STEM Education

Online asynchronous learning has become a central mode of instruction in higher education due to its flexibility, scalability, and accessibility for diverse student populations. Asynchronous courses allow students to access instructional materials at their own pace and time, making them particularly suitable for working professionals, nontraditional students, and those with family or geographic constraints [1], [2]. In engineering and STEM education, asynchronous delivery has supported continued access to coursework while addressing enrollment growth and resource limitations [2], [4]. Despite these advantages, studies have raised concerns regarding the quality of learning experiences in asynchronous environments. Researchers have reported challenges related to limited instructor presence, reduced peer interaction, and delays in feedback, which can negatively affect student satisfaction and learning outcomes [3], [4]. These challenges are especially pronounced in technically rigorous disciplines, such as engineering, where students often require iterative explanations and guided problem-solving to master complex concepts [5].

Student engagement and motivation are widely recognized as critical factors influencing success in online learning environments. Engagement in online courses has been associated with improved academic performance, persistence, and satisfaction [10]. However, maintaining engagement in asynchronous courses remains challenging due to the absence of real-time interaction and structured accountability [11]. Prior research has shown that students in online settings may experience reduced motivation and increased feelings of isolation when opportunities for interaction with instructors and peers are limited [3]. Working students, in particular, often struggle to balance academic responsibilities with professional and personal commitments, which may further reduce their ability to actively engage in online coursework [6]. These findings underscore the need for instructional strategies that promote autonomy while also fostering meaningful interaction and motivation. The flipped classroom model has gained significant attention as an instructional approach designed to promote active learning and student engagement. In this model, students are introduced to core content through pre-class materials, such as video lectures, while scheduled class time is dedicated to interactive activities, discussion, and problem-solving [7]. Within engineering education, flipped instruction has been associated with increased student engagement, improved conceptual understanding, and enhanced learning outcomes [8], [9].

Most existing research on flipped classrooms has focused on face-to-face or hybrid instructional contexts. Studies have demonstrated that flipped models can effectively support active learning in blended environments by reallocating instructional time and encouraging student-centered learning [12]. More recent work has explored flipped approaches in online courses; however, these implementations frequently rely on synchronous sessions as the primary venue for interaction [13]. Although prior studies highlight the potential benefits of flipped classroom models, limited research has examined their application within fully asynchronous online courses, particularly for working and remote students. Much of the existing literature assumes the presence of regular synchronous meetings, which may not be feasible or effective for learners with competing responsibilities [6], [13]. Additionally, few studies systematically examine how flipped instructional designs influence learning support, convenience, motivation, and perceived challenges specifically within asynchronous environments.

To address this gap, the present study investigates the effectiveness of a flipped classroom model implemented in a fully asynchronous online course with limited synchronous components. By focusing on working and remote students and using pre- and post-survey data, this study contributes to the engineering and STEM education literature by providing empirical evidence on how flipped instructional strategies can enhance engagement and learning in asynchronous contexts. Specifically, the study investigates students' perceptions of learning support, convenience, motivation, and challenges associated with the flipped instructional design in a remote learning environment. To address these objectives, the study is guided by four research questions: ***how the flipped classroom supports student learning in a remote environment, how convenient the flipped classroom model is for students' engagement with course materials, how the flipped classroom model affects student motivation, and what challenges students face in online learning and how the flipped approach mitigates these challenges.***

3. Course Design and Instructional Framework

3.1 Course Context

The study was conducted in an upper-level undergraduate/graduate-level data analytics course within a STEM discipline, delivered in a fully online asynchronous format at a large public university in the United States. The course enrolled working and remote students, many of whom balanced academic responsibilities with employment and personal commitments. To accommodate these learners, the course was intentionally designed to minimize required real-time attendance while maintaining instructional quality and engagement. All instructional content was delivered asynchronously through the learning management system, with optional synchronous review sessions and virtual office hours offered as support mechanisms. The flipped classroom model was implemented as the primary instructional framework to support flexibility, accessibility, and active learning in an asynchronous learning environment.

3.2 Flipped Classroom Model Implementation

The flipped classroom model was structured to shift direct instruction to asynchronous activities while reserving limited synchronous time for interaction, clarification, and application. The instructional design consisted of the following core components.

Pre-Recorded Video Lectures

For each instructional module, the instructor provided pre-recorded video lectures covering key concepts and foundational content in data analytics. These videos served as the primary source of direct instruction and were made available in advance of weekly activities. Students were encouraged to watch the videos at their own pace and were able to pause, rewind, and rewatch content as needed. Supplementary materials, such as presentation slides, example files, and reference documents, were provided alongside the videos to support different learning preferences and levels of prior experience.

Weekly Live Discussions

Although the course was primarily asynchronous, weekly live discussion and review sessions were offered to support interaction and instructor presence. These sessions focused on addressing student questions, reinforcing key concepts from the video lectures, and discussing applied examples related to assignments and projects. Attendance was encouraged but not required, recognizing that not all students could consistently participate due to work or scheduling constraints. Recordings of the live sessions were made available to ensure equitable access for all students.

Quizzes, Assignments, and Projects

Periodic quizzes, weekly tests, structured assignments, and applied mini-projects were used to reinforce learning and promote continuous engagement with course content. Assessment strategies were intentionally aligned with the flipped instructional model, with quizzes and weekly tests designed to assess comprehension of key concepts introduced in the pre-recorded video lectures. Assignments and mini-projects emphasized application, problem-solving, and hands-on analysis using data analytics tools and techniques. In some cases, helper sheets, guided examples, and scaffolded resources were provided to support student learning and reduce cognitive overload. Major course projects were used to assess cumulative understanding and the practical application of course concepts in authentic data analytics contexts. Deadlines were structured to provide flexibility for working students while maintaining consistent pacing throughout the course.

Examinations

The course included two major examinations designed to assess cumulative understanding of course material. Exams emphasized conceptual understanding and application rather than memorization and were aligned with the learning objectives addressed through the flipped instructional activities. Students were provided with clear guidelines and sufficient preparation time to support success in the asynchronous learning environment. Although this study did not formally evaluate hands-on learning and peer-to-peer collaboration outcomes, the course design incorporated both elements. Students completed a collaborative mini-project in small teams (two to three members) that required shared problem-solving and coordinated deliverables. In addition, virtual lab sessions were conducted to provide hands-on Python programming experience using industry-relevant tasks, thereby supporting applied learning within the asynchronous format. The effectiveness of these components will be systematically assessed in future course offerings as part of an ongoing continuous improvement initiative.

3.3 Role of Asynchronous and Synchronous Components

Asynchronous components, including pre-recorded video lectures, quizzes, assignments, and recorded discussion sessions, formed the foundation of the course and enabled students to engage with instructional content on their own schedules. The course was officially designated as online and asynchronous, with all core materials delivered through the learning management system. Synchronous elements, such as weekly review sessions and virtual office hours, were intentionally limited and offered as optional support mechanisms rather than required class meetings. These synchronous components were used strategically to enhance interaction, provide clarification, and foster a sense of learning community without imposing rigid attendance requirements. This balance was designed to support working and remote students while preserving opportunities for engagement and instructor feedback.

3.4 Alignment with Learning Objectives

All instructional components were intentionally aligned with the course learning objectives. Pre-recorded videos introduced foundational concepts, quizzes assessed understanding, assignments and applied projects supported skill development and practical application, and live discussions provided opportunities for clarification and deeper exploration. The flipped classroom framework ensured that each activity served a clear instructional purpose and contributed to students' overall learning outcomes. This alignment was critical in maintaining instructional coherence and supporting student success in a fully asynchronous online learning environment.

4. Methodology

The study involved **twenty students (n = 20)** enrolled in a fully online asynchronous STEM course at a large public university in the United States. The course primarily served working and remote students who selected the asynchronous format to accommodate professional, personal, and scheduling constraints. Participation in the study was voluntary, and all students enrolled in the course were invited to complete both the pre- and post-surveys. Only students who completed both surveys were included in the final analysis.

This study employed a pre–post survey research design with a quantitative approach to examine changes in students' perceptions following the implementation of the flipped classroom model. Pre–post designs are commonly used in educational research to assess the impact of instructional interventions on learner perceptions and experiences over time **[14], [15]**. The pre-survey was administered at the beginning of the course to capture baseline perceptions of online learning, while the post-survey was administered at the conclusion of the course to evaluate students' experiences with the flipped instructional model, enabling direct comparison of student responses before and after the instructional intervention. Although the study primarily employed a quantitative pre–post survey design, open-ended reflection questions were included to provide contextual insight and support interpretation of the quantitative findings.

Data were collected using a structured survey instrument consisting of Likert-scale items aligned with the study's research questions. The survey measured four primary constructs: **learning efficiency**, examining students' perceived understanding and ability to learn course content; **course content quality**, focusing on the clarity, organization, and alignment of instructional materials; **instructional effectiveness**, including perceptions of instructor support and course structure; and **multimedia quality**, addressing video usability, accessibility, and flexibility. All Likert-scale items used a 5-point scale ranging from 1 (Strongly Disagree) to 5 (Strongly Agree). The survey constructs were informed by prior research on online learning quality, student engagement, and instructional effectiveness in technology-mediated environments **[3], [16], [2]**.

The pre-survey was distributed electronically during the first week of the course, prior to the full implementation of the flipped classroom model. The post-survey was administered during the final week of the course after students had completed all instructional activities, assignments, and examinations. Survey responses were collected using an online survey platform. To encourage honest feedback, responses were anonymized, and students were informed that participation and survey responses would not affect their course grades. Completion of each survey required approximately 10–12 minutes.

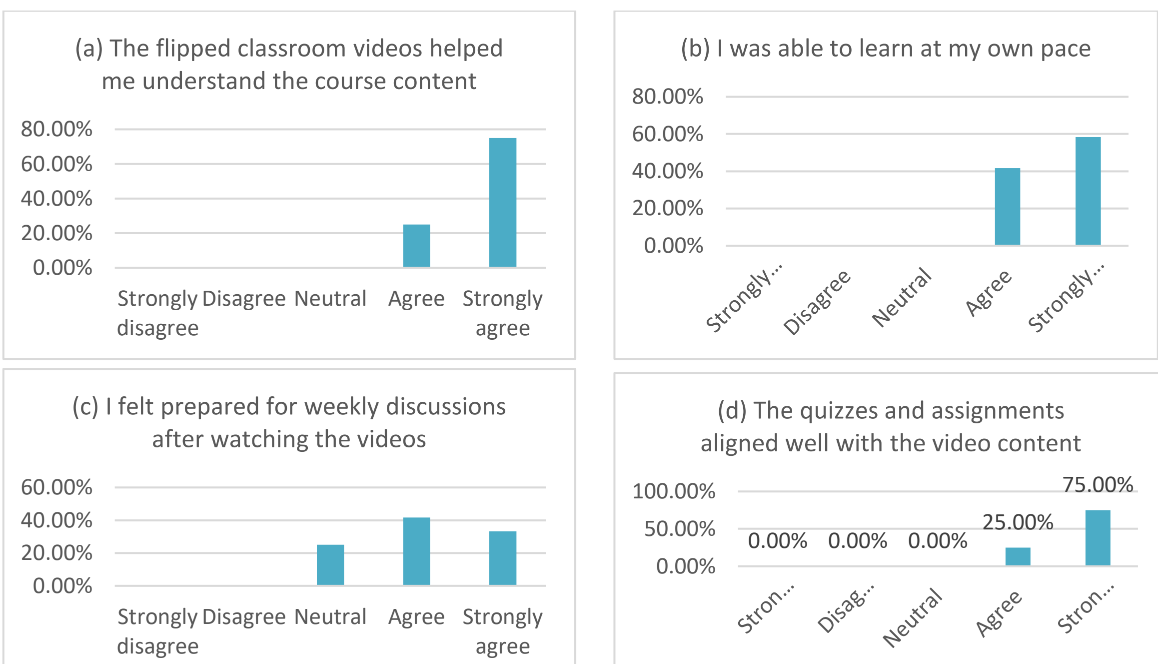

Figure 1**.** Post-survey results for learning efficiency outcomes, including perceived understanding, self-paced learning, and alignment between instructional videos and assessments.

Quantitative data analysis focused on descriptive and comparative statistics. Descriptive statistics, including means, standard deviations, and response distributions, were calculated for each survey item and construct to summarize overall trends in student perceptions. Pre- and post-survey responses were compared to examine changes associated with the flipped classroom intervention. Given the exploratory nature of the study and the relatively small sample size, the analysis emphasized trend-based and paired comparisons where appropriate, consistent with recommended practices in engineering education research for small-scale instructional studies [17]. Results were organized and reported according to the four research questions to ensure alignment between the research design, analysis, and findings.

5. Results

5.1 Learning Efficiency Outcomes (RQ1)

Pre-survey results indicated that students entered the course with limited confidence in key technical areas. Mean ratings for programming knowledge (M = 2.06) and data analytics concepts (M = 2.79) on a 5-point Likert scale suggest relatively low perceived preparedness at the start of the course. These baseline results establish the need for instructional approaches that support foundational learning in a remote environment.

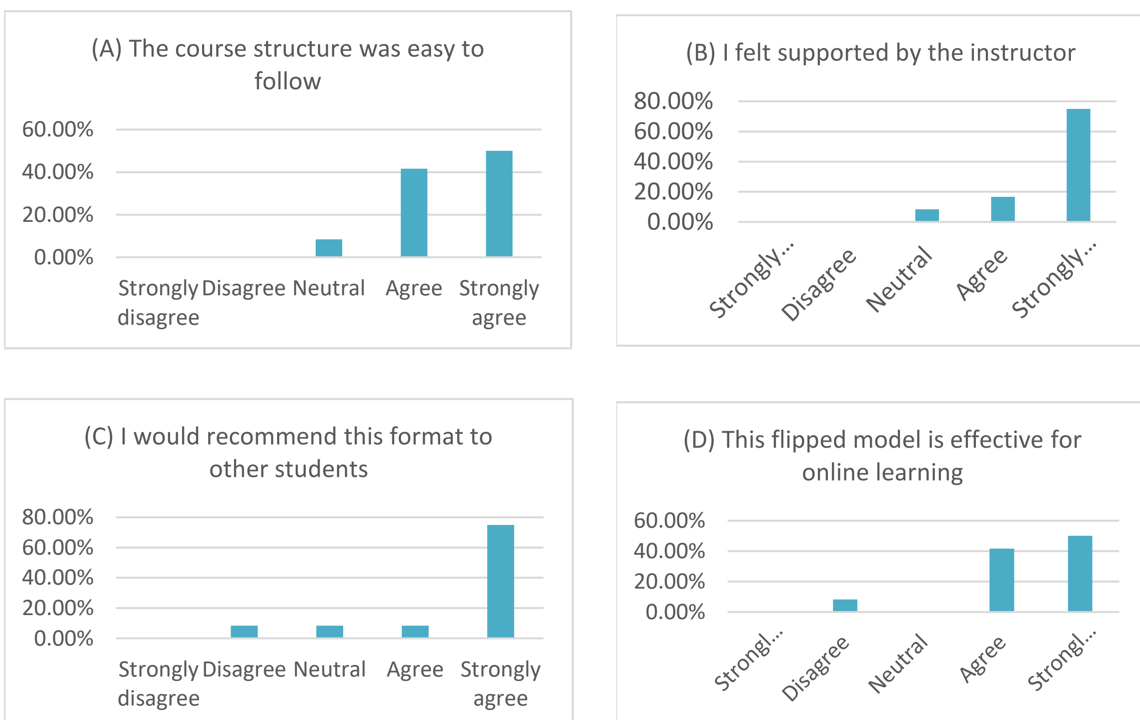

Figure 2. Post-survey results related to course organization, instructional support, and perceived effectiveness of the flipped classroom model.

Post-survey results demonstrated substantial improvement in perceived learning efficiency following the implementation of the flipped classroom model. As shown in Figure 1, students strongly agreed that the pre-recorded videos helped them understand course content (M = 4.75) and enabled self-paced learning (M = 4.58). A high level of agreement was also observed for preparedness for weekly discussions after viewing the videos (M = 4.08). In addition, alignment between quizzes, assignments, and video content was rated very positively (M = 4.75), indicating effective reinforcement of key concepts. These results indicate that the flipped classroom model effectively supported student learning and comprehension in a fully online asynchronous setting.

5.2 Course Content and Instructional Quality (RQ2)

Students evaluated course content organization and instructional quality positively in the post-survey. As illustrated in Figure 2, the course structure was rated as easy to follow (M = 4.42), and students reported feeling well supported by the instructor throughout the course (M = 4.67). These results suggest that instructional clarity and instructor presence were maintained despite the absence of required real-time class meetings.

Alignment between instructional materials and assessments was also rated highly, supporting a coherent learning progression. Overall perceptions of effectiveness were strong, with students agreeing that the flipped classroom model was effective for online learning (M = 4.33) and indicating a willingness to recommend the course format to other students (M = 4.50). Response distributions show that the majority of students selected "Agree" or "Strongly Agree" for both items, reinforcing the consistency of these findings.

5.3 Multimedia Quality and Accessibility (RQ3)

Multimedia quality and accessibility emerged as the strongest outcome area in the post-survey results. As shown in Figure 3**,** students overwhelmingly agreed that the ability to pause, rewind, and review video lectures enhanced their learning experience (M = 4.92), representing the highest mean score among all survey items. This finding highlights the importance of flexible multimedia design in asynchronous instruction.

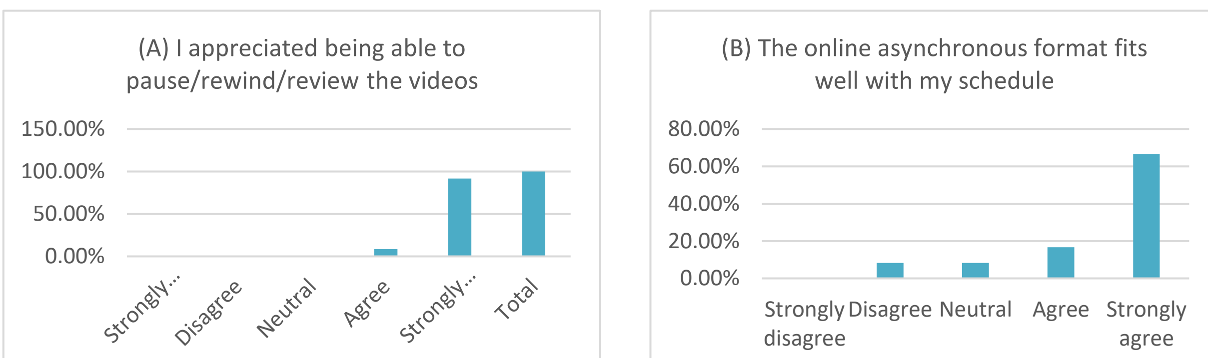

Figure 3. Post-survey results illustrating student perceptions of multimedia quality, accessibility, and schedule flexibility.

Students also reported that the asynchronous format fit well with their schedules (M = 4.42), a particularly important result given that over 84% of participants reported being employed while enrolled in the course. These findings underscore the role of accessible, high-quality multimedia resources in supporting learning for working and remote students in online STEM courses.

5.4 Student Motivation and Engagement (RQ4)

Post-survey results indicated positive trends in student motivation and engagement. As illustrated in Figure 4**,** students reported that the flipped classroom model increased their motivation to remain engaged with course activities (M = 4.42) and helped them stay motivated to complete tasks on time (M = 4.50).

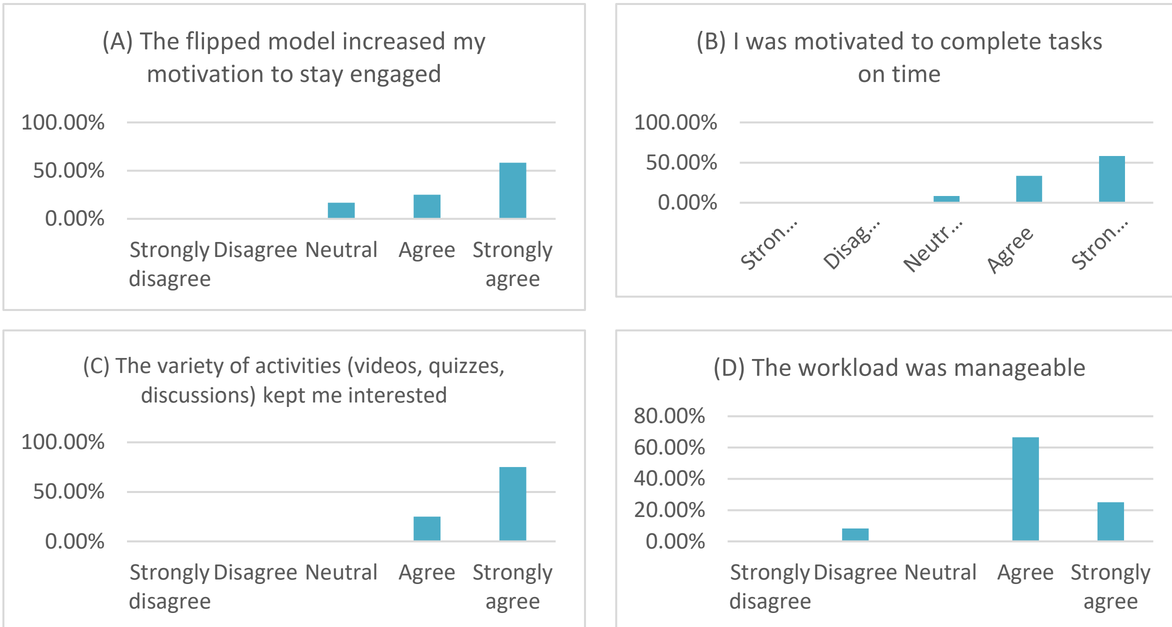

Figure 4. Post-survey results related to student motivation, engagement, and perceptions of instructional variety.

Students also rated the variety of instructional activities—including videos, quizzes, discussions, and assignments, very highly (M = 4.75), suggesting that the multimodal instructional design supported sustained interest throughout the semester. These quantitative findings are further supported by student reflections, which frequently emphasized flexibility, video-based instruction, and opportunities for content review as key contributors to engagement and reduced learning challenges.

6. Discussion

This study examined the effectiveness of a flipped classroom model implemented in a fully online asynchronous STEM course. The discussion interprets the findings in relation to the research questions and situates the results within existing literature on flipped instruction and online learning, with a particular focus on engineering and data analytics education.

The findings indicate that the flipped classroom model ***effectively supported student learning in a remote, asynchronous environment***. Pre-survey results showed that students entered the course with limited confidence in programming and data analytics concepts, highlighting the need for instructional approaches that provide flexibility and repeated exposure to foundational material. Post-survey results demonstrated strong agreement that pre-recorded videos improved understanding and supported self-paced learning, as reflected in high mean scores for learning efficiency and alignment between instructional videos and assessments. These findings align with prior research suggesting that flipped classrooms can enhance conceptual understanding by allowing students to engage with instructional content at their own pace before applying concepts through structured activities [7], [8]. In asynchronous settings, this instructional design appears particularly beneficial for STEM courses, where students often require additional time and repeated practice to master complex technical concepts.

Convenience and accessibility emerged as central strengths of the flipped classroom implementation. High ratings for multimedia quality, accessibility, and schedule flexibility indicate that students valued the ability to pause, rewind, and revisit video lectures. This finding is especially significant given that the majority of students were employed while enrolled in the course, making rigid synchronous attendance difficult. These results extend existing literature on online learning, which emphasizes flexibility as a key factor in supporting nontraditional and working students [2], [4]. Unlike synchronous online models that may inadvertently exclude students with scheduling constraints, the asynchronous flipped approach preserved access to instructional content while maintaining instructional coherence. The positive perceptions of course organization and instructional quality further suggest that asynchronous delivery does not inherently compromise structure or instructor presence when thoughtfully designed.

Student motivation and engagement were positively influenced by the flipped classroom model. Post-survey results indicated that students felt more motivated to remain engaged and complete tasks on time, and they rated the variety of instructional activities very highly. These findings suggest that the multimodal design, combining videos, quizzes, assignments, discussions, and projects, helped sustain interest and promote active participation. Student reflections further support this interpretation, as many participants emphasized flexibility, video-based instruction, and scaffolded assignments as factors that reduced overwhelm and increased engagement. These results are consistent with prior studies showing that active and varied instructional strategies can enhance motivation in online learning environments [10], [3]. For asynchronous STEM courses, where disengagement is a common concern, the flipped model may offer a practical strategy for fostering sustained participation.

Addressing common challenges in online STEM learning emerged as a central theme in students' experiences with the flipped classroom model. Although students reported challenges commonly associated with online STEM courses, such as learning programming concepts, managing workload, and occasional technical issues, the flipped classroom model helped mitigate these challenges. Students noted that repeated access to videos, helper materials, and scaffolded assignments enabled them to overcome difficulties and better manage their learning. Several students also described how becoming familiar with the course rhythm improved their time management over the semester. These findings align with research suggesting that flipped and learner-centered instructional designs can reduce cognitive overload and support learner autonomy [18]. While challenges were not eliminated entirely, the flipped approach provided mechanisms that allowed students to adapt, persist, and succeed in a fully asynchronous environment.

Effectiveness of flipped instruction in fully asynchronous STEM courses emerged as a key outcome of this study. While much of the existing flipped classroom literature focuses on face-to-face or hybrid learning environments, the findings provide empirical evidence that flipped instructional strategies can be successfully implemented in fully asynchronous courses without reliance on mandatory synchronous sessions. Strong student agreement regarding the effectiveness of the course design and their willingness to recommend the format suggests that flipped models can sustain instructional quality, engagement, and motivation even in the absence of real-time instruction. These findings are particularly relevant for engineering and STEM programs seeking to expand online offerings while effectively supporting working and remote student populations.

Implications for engineering and STEM education highlight the potential of asynchronous flipped classroom models as effective and scalable instructional frameworks. The findings of this study suggest that well-designed asynchronous flipped courses can support flexibility without compromising rigor by emphasizing high-quality multimedia resources, structured and aligned assessments, and clear learning objectives. For engineering and STEM instructors, adopting flipped instructional strategies may enhance engagement and learning while accommodating the needs of working and remote students. At the institutional level, supporting flipped course development through instructional design assistance, multimedia production resources, and professional development can further strengthen the quality and sustainability of online STEM programs.

7. Challenges and Limitations

This study provides useful insights into the effectiveness of a flipped classroom model in a fully online asynchronous course; however, several limitations should be considered. The small sample size of approximately twenty students limits the generalizability of the findings, and future studies across multiple courses or institutions would strengthen external validity. The small sample also limits statistical power and increases the possibility that results reflect course-specific conditions rather than broadly applicable trends. Therefore, the findings should be interpreted as exploratory and preliminary rather than definitive evidence of effectiveness. Replication with larger and more diverse samples across multiple courses and institutions is needed to strengthen external validity. The investigation was also confined to a single STEM course at one institution, meaning that course design, instructor practices, and student demographics may have influenced the results and limit transferability to other contexts. In addition, the study relied primarily on self-reported survey data, reflecting student perceptions rather than objective learning outcomes, which may introduce response bias.

The study did not include a comparison group (e.g., a traditional asynchronous course without a flipped design). Thus, it is not possible to attribute observed improvements solely to the flipped classroom model, as other factors such as course organization, instructor support, or student characteristics may also have influenced outcomes. Future research using experimental or quasi-experimental designs with control groups would allow for stronger causal inferences regarding the specific contribution of flipped instructional strategies.

Although perception data provide valuable insight into student experiences and satisfaction, they may not fully reflect actual learning gains or skill development. Students' positive perceptions do not necessarily guarantee improved academic performance. Future research should incorporate objective measures such as course grades, performance assessments, concept inventories, or longitudinal achievement data to more rigorously evaluate the effectiveness of asynchronous flipped instruction. Incorporating performance-based measures in future work would strengthen the evidence. Technology and scheduling challenges, including audio quality issues and time-management constraints, may have further affected student experiences. Despite these limitations, the study contributes meaningful evidence to the growing literature on effective flipped classroom implementation in online engineering and STEM education.

8. Implications and Recommendations

The findings of this study suggest several important implications for the design and delivery of fully online asynchronous courses, particularly within engineering and STEM education. At the instructional level, the results emphasize the importance of prioritizing high-quality, well-structured pre-recorded video lectures that clearly introduce foundational concepts. The ability for students to pause, rewind, and revisit instructional videos emerged as a critical feature supporting self-paced learning, especially when engaging with complex technical content such as programming and data analytics. Supplementary instructional resources, including presentation slides, worked examples, datasets, and guided helper sheets, further supported understanding and reduced cognitive load by providing additional scaffolding and reference points for learners.

Alignment between instructional materials and assessments also played a key role in the effectiveness of the asynchronous flipped classroom model. Quizzes, assignments, and mini-projects that directly reinforced concepts introduced in the video lectures supported incremental learning and enabled students to monitor their own progress throughout the course. In addition, offering optional or limited synchronous sessions for clarification and interaction helped maintain instructor presence and opportunities for engagement without imposing rigid attendance requirements. Recording these sessions ensured equitable access for students who were unable to participate in real time due to work or scheduling constraints.

From a course design perspective, the findings highlight the need for intentional structure and pacing in asynchronous flipped courses. Consistent weekly module layouts, clear expectations, predictable deadlines, and balanced workloads supported students' time management and reduced confusion. These design considerations were particularly important for students with limited prior experience in programming or data analytics. Breaking longer video lectures into shorter segments, carefully sequencing learning activities, and providing guidance on expected time commitments improved accessibility and helped prevent students from feeling overwhelmed.

At the institutional level, the study underscores the critical role of support structures in sustaining high-quality asynchronous flipped learning environments. Access to instructional design expertise, multimedia production tools, and professional development focused on online pedagogy can significantly enhance the quality and consistency of flipped course materials. A robust technology infrastructure that supports reliable video hosting, discussion facilitation, and learning analytics is also essential. For institutions serving a high proportion of working and remote students, policies that promote flexible course scheduling and support asynchronous instructional models may further enhance student engagement, retention, and overall success in engineering and STEM education.

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