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Reforming First-Year Engineering Mathematics Courses: A Study of Flipped-Classroom Pedagogy and Student Learning Outcomes

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Abstract

Core mathematics courses are fundamental to the academic success of engineering students in higher education. These courses equip students with skills and knowledge applicable to their specialized fields. However, first-year engineering students often face significant challenges in mathematics due to a range of factors, including insufficient preparation, mathematics anxiety, and difficulty connecting theoretical concepts to real-life applications. The transition from secondary to tertiary mathematics remains a key area of educational research, with ongoing discussions about effective pedagogical approaches for teaching engineering mathematics. This study utilized a belief survey to gain general insights into the attitudes of first-year mathematics students towards the subject. In addition, it employed the activity theory framework to conduct a deeper exploration of the experiences of first-year engineering students, aiming to identify contradictions, or "tensions," encountered within a flipped-classroom learning environment. Quantitative data were collected using surveys that assessed students' self-reported confidence, competence, and knowledge development. Results from Friedman's and Wilcoxon's Signed-Rank Tests, conducted with a sample of 20 participants in 10 flipped-classroom sessions, statistically showed significant improvements in all three areas. All of Friedman's test statistics were above 50, with p-values below 0.05, indicating meaningful progress. Similarly, Wilcoxon's Signed-Rank Test results supported these findings, with p values under 0.05, leading to the rejection of the null hypothesis. The qualitative data, derived from student questionnaire comments and one-to-one interviews, elucidated critical aspects of flipped-classroom delivery. The analysis revealed emerging contradictions ("tensions") that trigger "expansive learning". These tensions encompassed the following: student expectation–curriculum structure; traditional versus novel delivery systems; self-regulation and accountability; group learning pace versus interactive learning; and the interplay between motivation and anxiety. These tensions are vital for academic staff and stakeholders to consider when designing and delivering a first-year mathematics course. Understanding these dynamics can lead to more effective, responsive teaching practices and support student success during this crucial transition phase.

Keywords: first-year transition; confidence; learner beliefs; competence; engineering mathematics; learning support; activity theory; contradictions; flipped classroom

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1. Introduction

Core mathematics courses play a critical role in the academic success of students enrolled in engineering programs (Silverstein & Baker, 2003). These foundational courses facilitate the development of student knowledge and skills in comprehending how mathematical and scientific principles are applied in the design and development of real-world projects (Flegg et al., 2012; Kirschenman & Brenner, 2010). However, it has been widely observed that first-year engineering students frequently encounter challenges in mathematics due to several factors. These include inadequate prior preparation, difficulty connecting theoretical concepts with practical applications, gaps in prior academic learning, and a general lack of confidence in their mathematical abilities (Cooper et al., 2021; Harris et al., 2015; Jablonka et al., 2017).

In the Australian context, this issue has been further exacerbated by the widespread removal of formal mathematics prerequisites for many university programs. Several institutions have adopted an "assumed knowledge" model, which suggests but does not require prior exposure to specific mathematical content (King & Cattlin, 2015). Consequently, students entering mathematics-intensive degrees often display widely varying levels of proficiency, leading to high rates of difficulty in foundational mathematics courses. Many students withdraw, fail to pass these courses, or ultimately change programs altogether (King & Cattlin, 2015; Woolcott et al., 2019). The transition from secondary school to tertiary mathematics and the level of student preparedness for this shift remains a longstanding concern and a focal point of educational research (Harris et al., 2015; Harris & Pampaka, 2016; Jourdan et al., 2007). Notably, the average graduation completion rate for engineering students in Australia is approximately 54%, a statistic that underscores a significant attrition rate and represents a substantial loss to Australia's workforce (Godfrey et al., 2010).

There has been ongoing debate regarding the most effective methods of teaching engineering mathematics and the pedagogical approaches that best support students in learning this field (Faulkner et al., 2019; Pepin et al., 2021). Despite numerous studies exploring various instructional strategies in higher education, significant challenges and gaps remain. One emerging approach is the flipped-classroom model, which shifts the focus toward student-centered learning through a blended learning instructional format. This method was first introduced by a teaching–learning approach started by Bergmann and Sams (2012), who observed that students struggled to apply information from traditional lectures when completing homework tasks. The fundamental principle of the flipped-classroom model involves reversing the traditional instructional approach. Educational content that is usually presented during in-class sessions is instead accessed by students outside of classroom hours, allowing class time to be dedicated to interactive and applied learning activities. This approach is commonly described as a "flipped" instructional strategy. According to Bergmann and Sams (2012), the concept is based on switching what was traditionally covered in class to be completed at home and what was completed as homework to be covered in class. However, as noted by Bishop and Verleger (Lo & Hew, 2017), the flipped-classroom approach has its challenges. These include increased workload for instructors, student disengagement, and lack of preparation for pre-class activities, all of which can hinder its effectiveness.

The objective of this study is to employ the activity theory framework to examine the experiences of first-year engineering mathematics students as they transition from traditional lecture–tutorial instruction to a flipped-classroom model. Rooted in L. Vygotsky's (1978) concept of culturally mediated actions, cultural–historical activity theory (CHAT) was expanded by Engeström (2014b) to incorporate a broader social context of the individual interactions. Engeström (2014b) identifies four levels of internal contradictions that learners may encounter and attempt to resolve during the learning process. Past studies

(Gedera, 2016; Murphy & Rodriguez-Manzanares, 2008) have effectively applied activity theory to educational research, demonstrating its value in exploring complex learning environments. In this study, the focus is on understanding students' beliefs about mathematics, examining their experiences with the newly implemented flipped-classroom approach, identifying contradictions ("tensions") within the activity system, and analyzing how these "tensions" (contradictions) influence their learning and transition into higher education. The research questions guiding this study are as follows:

1. What contradictions ("tensions") emerge when students participate in a flipped-classroom approach in a first-year engineering mathematics course?
2. How do students develop confidence, competence, and knowledge while navigating these contradictions ("tensions") within a flipped-classroom setting?

This report presents findings from a mixed-methods study aimed at documenting students' experiences and learning transition. This study identifies key emerging contradictions and offers pertinent recommendations to address them. The findings of this research intend to offer valuable insights into the dynamics of first-year learner experiences, thereby informing improvements in course design and delivery to enhance students' learning and transition. This paper is structured as follows: Section 1 presents the existing problem and the literature review. Section 2 provides the theoretical framework and background, teaching approaches, context of this research study, and participants' backgrounds. It highlights the key aspects of student learning models and their conceptual basis, flipped-classroom approach, and research problem. Section 3 covers the materials and methods. This section provides information on the ethics, participants' backgrounds, course information, and methodology. Section 4 presents the results and discussion of the qualitative and quantitative data. It includes graphical and statistical analyses of the collected dataset. It also includes discussion and recommendations based on the outcomes of this research study. Finally, Section 5 provides a comprehensive conclusion, summarizing the findings of this study.

2. Theoretical Framework and Research Background

2.1. Theoretical Framework Background

The theoretical foundation of this study draws upon activity theory, which builds upon the cognitive constructivism framework derived from Piaget (1976). Piaget asserted that internal mental processes mediate the relationship between an external stimulus and responses, emphasizing that learning occurs through modification of existing cognitive structures or schemata as individuals assimilate and accommodate new information (Skinner, 1985). Expanding upon this framework, L. Vygotsky (1978) introduced the cultural–historical activity theory, which was later developed further by his colleague Alexei Leont'ev (1981). Vygotsky emphasized the importance of social interaction and cultural context in learning, proposing a triad relationship among the subject (learner), the object (goal or task), and mediation (tools or artefacts). Central to his theory is the concept of the Zone of Proximal Development (ZPD), which posits that learning is most effective when it occurs through collaboration with others, particularly with more knowledgeable peers or instructors, and is supported by mediating tools or structured activities (Kozulin, 2014).

In this context, learning is facilitated through continuous feedback between the learner and the expert, engaging two key cognitive processes: assimilation and accommodation. Engeström (2001) later conceptualized this framework as the first generation of activity theory, describing it through the model of the "mediated act", which highlights the dynamic interaction between individuals and their environment in the learning process.

The key limitation of the above model, outlined by the theorists, was its predominant focus on the individual as the central unit of analysis. This limitation was later addressed by

Luria (1971) and Alexei Leont'ev (1981), who expanded the model by incorporating other important elements of cultural, social, and historical dimensions into the understanding of human actions. In this extended framework, the individual is interpreted through the lens of their cultural context, and the object of activity is viewed as a culturally embedded entity. Alexei Leont'ev (1981) made a crucial distinction between an individual action and a collective activity, highlighting the importance of social context in understanding human behavior.

Building on these developments, Engeström (2001) further expanded the original triad model (Figure 1) into a more comprehensive framework by introducing three additional components: rules, community, and division of labor (Figure 2). In this revised model, the subject may refer to the individual or subgroup engaged in the activity, the *object* refers to the "problem space" toward which the activity is directed, and this is ultimately transformed into outcomes through the use of mediating artefacts (tools or instruments) (Ashwin, 2012; Engeström, 2001). The *community* consists of individuals or groups who share the same general object. The *division of labor* encompasses both the horizontal division of tasks among members of the community and the vertical stratification of roles, power, and status. *Rules* within the activity system refer to the explicit and implicit norms, regulations, and conventions that govern the actions and interactions.

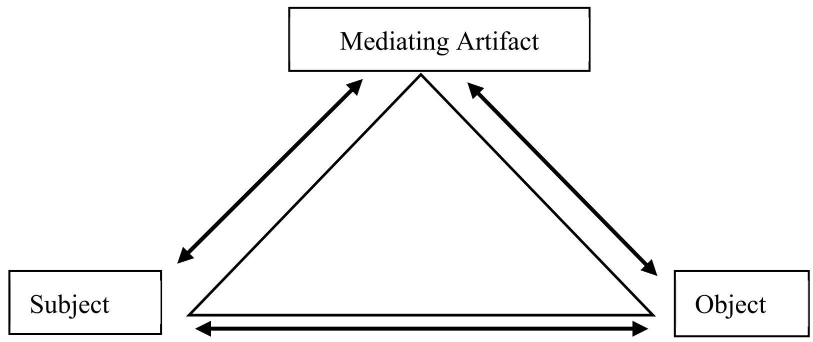

Figure 1. Vygotsky's idea of cultural mediation of actions shown as a triad of subject, object, and the mediating artifact.

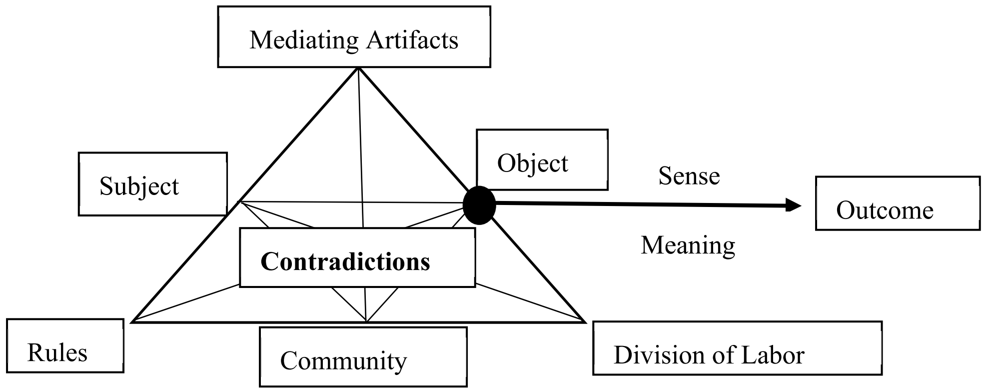

Figure 2. The structure of the activity system (Engeström, 2001).

According to Engeström (2001), activity theory needed to be expanded to account for a broader context of an individual's interactions within their social environment, mediated through artifacts and situated within a specific activity setting. To capture this complexity, the model was extended to depict human activity as occurring across two or more interacting activity systems. In his report on a hospital project, Engeström (2001) demonstrated how two or more activity systems (such as Physicians, General Practitioners, Patients, and Families) can change and lead to "expansive learning". This framework can also be applied effectively to an educational setting. All elements in a classroom setting have a cultural and social meaning. Prior research has employed dual-activity systems to explore learning contexts, such as learning within a mathematics module (Jaworski et al., 2012), and contradictions experienced by first-year undergraduates transitioning from school to university-level mathematics (Jooganah & Williams, 2016). Similarly, Anastasakis et al. (2022) adopted activity theory to investigate challenges faced by students learning engineering mathematics at university. Following Ashwin (2012), we also treat our activity systems as contextually generic with respect to the existing literature. The model depicted in Figure 3 illustrates these two interacting systems.

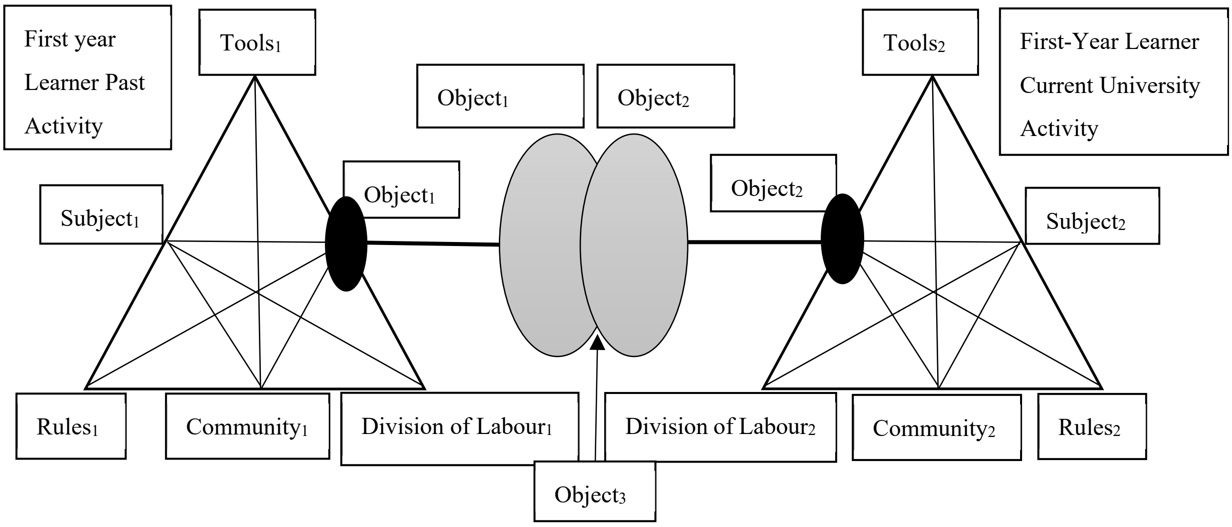

Figure 3. The structure of two interacting activity systems in third-generation activity theory (Engeström, 2001).

2.2. Activity System in the Context of Study

Engeström (2001) states contradiction as a central principle of the third-generation activity theory (Figure 4). It is often associated with concepts such as tension, dichotomy, opposition, and misalignment (Engeström & Sannino, 2011). Contradictions are distinct from problems or conflicts; they represent historically accumulated structural tensions both within and between the activity systems. Kuutti (1996) describes contradictions as a general misalignment within and between the school and university, which offer valuable insight into students' difficulties in tertiary mathematics. Contradictions are not necessarily negative but important as they can result in change and development (Murphy & Rodriguez-Manzanares, 2008). However, transformation resulting from contradictions may not always occur; the impact whether it enables or hinders learning progress depends on its acknowledgment and solution (Nelson & Kim, 2001).

2.3. Contradictions

Contradictions within any component of the activity system should not be solely regarded as deficiencies; rather, they may present valuable opportunities for growth, innovation, and the development of new avenues of activity (Karanasios et al., 2017; Murphy & Rodriguez-Manzanares, 2008). Learning and transformation are often triggered by multi-level contradictions as the learner attempts to alleviate the "tensions" from "disturbances" (Foot & Groleau, 2011). According to Engeström (2014b), the cultural–historical activity theory (CHAT) identifies four levels of inner contradictions that can trigger learning. These are outlined in Table 1 below.

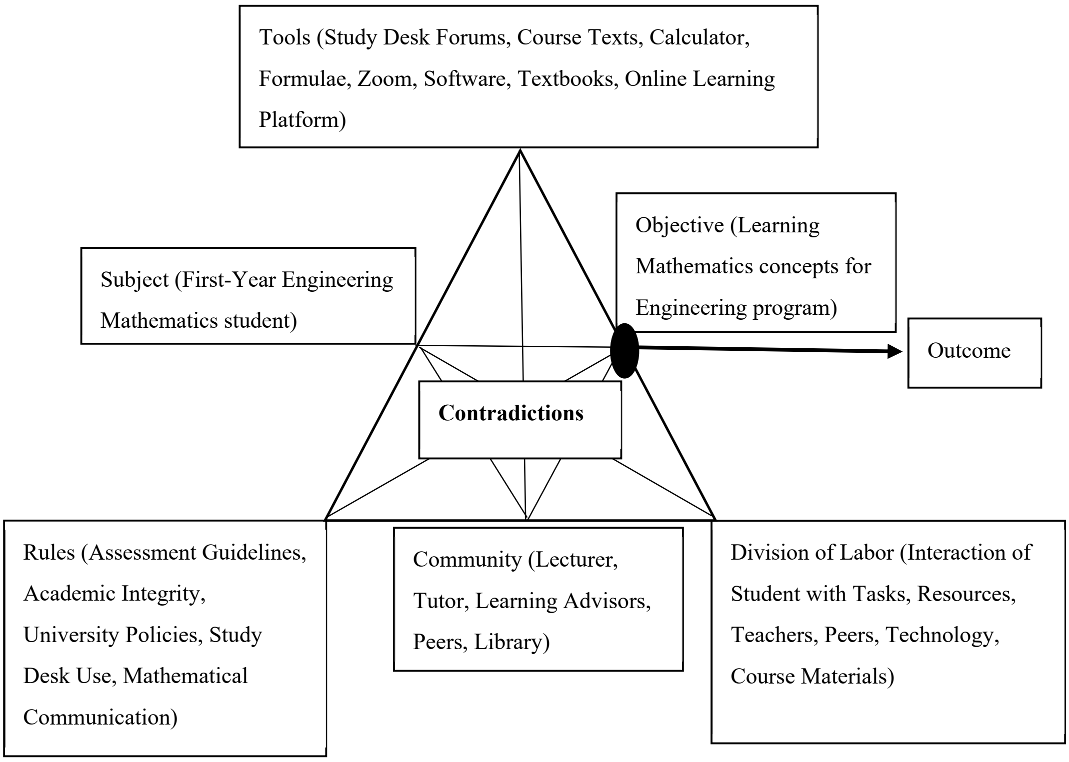

Figure 4. Proposed structure of first-year engineering mathematics activity system. Adapted from Engeström (2001).

Table 1. Engeström's (2014b) four levels of contradictions.

Primary Contradictions	Occur within the activity that brings about the conflict, where more than one value is associated with an element. The learner sees a contradiction between use value and exchange value.
Secondary Contradictions	Occur when the learner finds conflict in assimilating or integrating a new element.
Tertiary Contradictions	Occur when an advanced form of method emerges for achieving the objective.
Quaternary Contradictions	Occur between activities when the learner finds changes in an activity as conflicts with adjacent activities.

2.4. First-Year Teaching–Learning Approaches

Teaching and learning in first-year courses play a critical role in students' transition to tertiary study (Kift, 2015). In general, the quality of learning opportunities in these courses largely depends on classroom practices and adherence to established criteria for effective mathematics teaching (Durandt et al., 2022). Lecture and tutorial formats remain the most prevalent modes of teaching in tertiary institutions (Liu et al., 2023). Balwant and Doon (2021) state that the tutorial system formed the foundation of Oxbridge education and originated from the University of Oxford and University of Cambridge in the eleventh century. However, the definition of tutorial has become increasingly challenging with its contextual variability due to its flexibility and dynamics and inherent differences across disciplines (Balwant & Doon, 2021).

Generally, tutorials aim to complement lectures by enabling deeper interaction between the learners, concepts, and instructors (Balwant & Doon, 2021; Mason & Gayton, 2022). Traditional lectures, by contrast, are often characterized by a passive learning environment, with minimal learner interaction (Klein et al., 2023).

On the other hand, the flipped-classroom approach has emerged as an alternative that leverages technology to transform the learning process. This approach requires students to engage with instructional videos or other digital resources prior to class, shifting the acquisition of foundational knowledge outside the classroom. Consequently, in-class time is repurposed for active learning activities such as discussions, problem-solving, and collaborative group work. In this course, students were encouraged to view the recorded instructional videos made available by the educator on the online platform prior to class, allowing them to engage with the course content independently outside of the classroom setting. The conceptual foundations of flipped classrooms are underpinned by student-centered learning theories of Piaget (1967), L. S. Vygotsky and Cole (1978). As Gopalan et al. (2018) describe, flipped teaching is a hybrid approach that removes the lecture from the classroom. This change requires students to take responsibility to study independently by covering the basic knowledge of the weekly content in their own time (Gopalan et al., 2018). In turn, the weekly classroom sessions focus on higher-order cognitive skills, such as application, evaluation, and synthesis, aligned with the upper levels of Bloom's taxonomy (Street et al., 2015).

The strength of the flipped classroom lies in its focus on more active learning and greater student engagement (Steen-Utheim & Foldnes, 2018). In a study of twelve students in a Norwegian higher education institution (Steen-Utheim & Foldnes, 2018), students reported a higher engagement and positive learning experience in a two-semester-length mathematics course. It showed the affective dimension of student engagement was most prevalent with student reflection with the learning strategy. In another study at Flinders University in Australia (Smallhorn, 2017), the results showed positive attitudes towards the learning method. In a study by McLean et al. (2016), results showed that the most significant contribution was deep and active learning in the flipped environment. The concept of deep learning involves the learner's motivation to extract meaning, patterns, and monitor their understanding of the material (Entwistle, 2000; Zhou & Zhang, 2025). To compare lectures based on active and flipped classrooms in higher education, a study with participants in a second-semester computer programming course found active learning resulted in the highest mean scores for teaching, social, and cognitive presence (Kay et al., 2019).

2.5. Research Problem and Background

Students who enter engineering programs without the necessary prerequisite knowledge and skills are at a significantly higher risk of underperforming or dropping out, particularly in first-year mathematics courses (Galligan & Hobohm, 2015). A key contributing factor is often the time elapsed since they last studied mathematics, as well as the mismatch between their previous mathematics exposure and the level required for tertiary engineering studies. Entry into engineering programs occurs through diverse pathways, including domestic and international secondary schools and tertiary preparation programs. In the case of mature-age students, direct entry is permitted after time in the workforce. This diversity highlights the importance of identifying and addressing varying levels of mathematical preparedness (knowledge gaps) among students in the first-year mathematics engineering courses.

In addition, there is notable variability in the mathematical skills required across various courses and programs. For example, students enrolled in the same core mathematics course may be pursuing an associate degree or bachelor's degree in different engineering programs, each of which may demand differing depths and extents of conceptual understanding. Therefore, it is essential to acknowledge and accommodate this heterogeneity to support equitable and effective learning experiences in foundational mathematics education for engineering students. Learning calculus concepts is very important for students to successfully complete their program and graduate with an engineering degree. A study with first-year students found significant correlations between the differential calculus and the diagnostic mathematics knowledge test grades and the performance of engineering students in most of their first semester courses, especially those related to their engineering major (Morán-Soto et al., 2023).

3. Materials and Methods

3.1. Ethics

All student participants were recruited on a voluntary basis and provided informed consent prior to participating in this study. Their data remained de-identified to ensure confidentiality and anonymity throughout the research process. Participants were explicitly informed of their right to withdraw from this study at any time without penalty, and they were free to skip any survey questions they did not wish to answer. It was also made clear that participation in this study would not have an impact on their academic standing. Ethical clearance for this low-risk study was obtained from the University of Southern Queensland Human Research Ethics Committee (Project ID: H16REA221).

3.2. Participants' Backgrounds

The participating engineering students in this study were identified based on feedback from learning advisors and lecturers, who highlighted students exhibiting significant gaps in their mathematical understanding of first-year engineering mathematics concepts. A total of twenty engineering students took part in this study, with diverse educational backgrounds, over the course of two academic semesters (Table 2).

Table 2. Participants' backgrounds from the first-year course.

Student Background	Number of Participants	Age Range
Domestic Mature (Years left school > 5 years)	8	30–60
Domestic Secondary (Years left School < 2)	6	20–29
International (Years left School < 2)	6	20–29

3.3. Course Rationale and Mathematical Concepts

The engineering mathematics course is designed to equip students with essential mathematical knowledge and skills as they commence their tertiary studies in engineering and surveying. It also serves as a foundational unit for students who experience gaps in prerequisite knowledge required for more advanced engineering mathematics courses. By addressing these gaps, the course supports a smoother transition into their chosen programs of study through development of core mathematical competencies. Figure 5 illustrates the percentage weightage of the mathematical concepts covered in the course.

3.4. Methodology

The evaluation strategy adopted in this research employs a mixed-methods approach to comprehensively analyze student responses collected through research instruments (see Appendix A). This approach entails the systematic gathering of both qualitative and quantitative data. Specifically, data were gathered through teaching session surveys, interviews, and belief surveys during the transition from the traditional lecture–tutorial format to the flipped-classroom model in the first-year engineering mathematics course. The quantitative results in this study are derived from the analysis of the belief survey as well as the pre-, mid-, and post-session rating questions from the flipped-classroom survey. Course surveys are valuable in identifying potential mismatches between student expectations (subject) and their actual learning experience (object). According to Engeström's (2001) expanded activity theory, contradictions or mismatch can arise between any elements within an activity system. The questionnaire given to students aimed to capture these dynamics during the learning sessions in the course. Specifically, the pre-, mid-, and post-session evaluations were employed to assess changes in students' perceived knowledge, confidence, and competence in mathematical concepts throughout the learning sessions (Algarni & Lortie-Forgues, 2023).

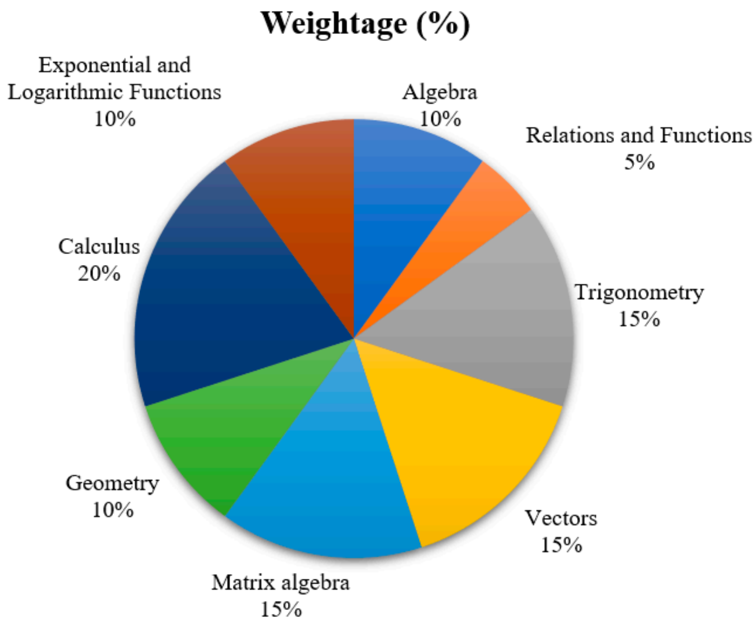

Figure 5. Percentage of mathematical concepts for the first-year engineering mathematics course. Calculus involves both differentiation and integration.

According to Durandt et al. (2022), the affective domain plays an important role in fostering both critical and creative thinking. The attitudinal dimension is particularly significant during transition from secondary and tertiary education as it encompasses a range of beliefs, attitudes, and emotions that influence learning (Leong et al., 2021). To explore the students' perspective on mathematics, this study utilized a belief survey focused on various dimensions of mathematical thinking and engagement. The survey was used to capture students' views on different aspects of mathematics, categorized as the following themes: Category 1, creativity and flexibility in mathematics; Category 2, rules, procedures, and structure in mathematics; and Category 3, professional or societal role of mathematics. The instrument proved effective in assessing learners' confidence, perceptions, attitudes, and anxiety about mathematics (Mazana et al., 2019). Each question was rated on a five-point Likert scale: *strongly agree* (5), *agree* (4), *neutral* (3), *disagree* (2), and *strongly disagree* (1). The full set of survey questions is presented in Table A1 in Appendix A.

The primary objective of statistical analysis in this study is to estimate key properties of the dataset, such as distribution patterns and differences between groups, to validate the hypothesis derived from the research questions. Nonparametric tests are used as it would be inappropriate to assume that the sample data drawn from the population followed a specific parametric distribution (Sijtsma & Emons, 2010). Norman (2010) states that nonparametric tests can be effectively used with Likert data with small sample sizes. This is also supported by Vrbin (2022) in the article containing recommendations for optimal data reporting in educational research. Accordingly, Friedman's test (Friedman, 1937) was utilized to compare three groups of the dataset (pre-, mid-, and post-session ratings), while Wilcoxon's Signed-Rank Test was applied between two related groups (pre- and post-session ratings). These tests were specifically applied to the knowledge rating averages collected across ten flipped-classroom sessions during the semester. Friedman's test effectively compared three dependent groups of data taken at three different points of collection (Chen et al., 2024). The null hypothesis posited that there was no significant change in learner knowledge because of the flipped-classroom methodology. Conversely, the alternative hypothesis proposed that a significant difference would exist.

Qualitative research plays a vital role in understanding the concepts, opinions, and experiences of students within the course. Open-ended responses are particularly valuable as they allow researchers to uncover learning- and transition-related issues that may not emerge through structured survey questions. This approach proved beneficial in providing deeper insights into the student experience. To explore students' deeper-level thinking, misconceptions, problem-solving strategies, and conceptual understanding, interviews were employed as an effective method to extract these valuable insights (Alamri, 2019). These interviews were conducted with the same students who participated in the flipped-classroom delivery approach in the first-year course. A semi-structured, one-to-one interview format was used to closely observe learners and identify any contradictions within their experiences. Table A2 in the Appendix A shows the general questions asked during the interview; however, participants were encouraged to freely share their learning experiences beyond the scope of the predefined questions. Additionally, the interviewer posed spontaneous, follow-up questions to facilitate deeper discussions and elicit further insights into the students' experiences.

4. Results and Discussion

4.1. Belief Survey Results

The belief survey provided valuable insight into students' perceptions of mathematics. Category 1 statements focused on beliefs around creative thinking and interpretation, originality, and multiple methods in mathematics. About 74% of responses were positive, with students selecting either agree (4) or strongly agree (5). Fewer than 10% of students expressed disagreement (selecting a 1 or a 2), suggesting that the majority appreciate the creative thinking and innovative aspects of mathematics. Students acknowledged that mathematical problems can be approached in multiple ways, and that trial-and-error is a valid and sometimes necessary strategy to arrive at a solution. Responses to these questions clustering towards the upper end of the scale reinforce an open and flexible attitude regarding mathematical problem-solving (see Figure 6).

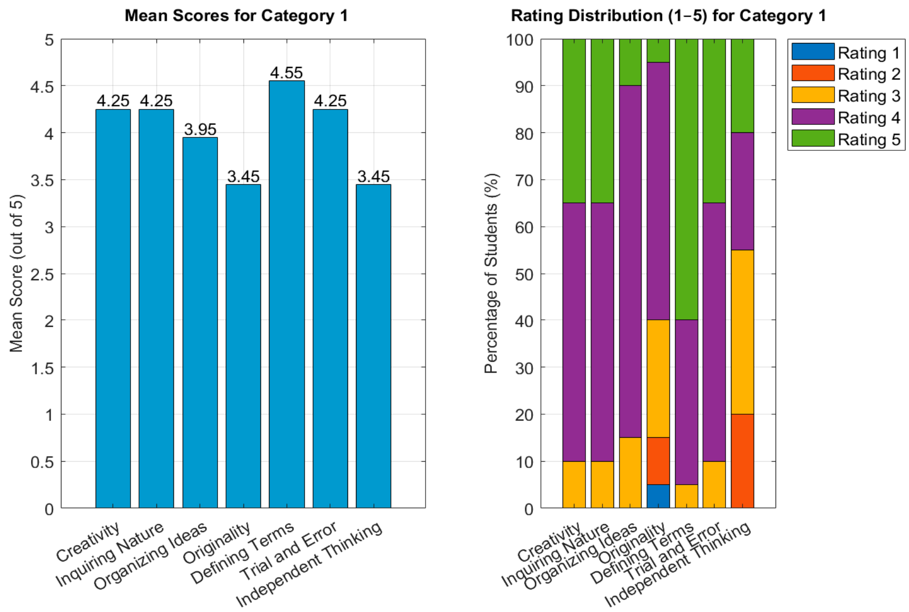

Figure 6. Mean and percentage rating distribution of Category 1 statements in the mathematics belief survey.

With respect to Category 2—probing beliefs around fixed laws, formulas, and routine procedures in mathematics—just under 70% of students agreed with the statements, suggesting that a substantial portion appreciate the rigor of mathematics and that there are (often strict) rules and procedures governing mathematical work. Approximately 12% of students expressed disagreement with the statements, indicating resistance to the notion that mathematics is purely procedural, or rule-bound. Notably, students tended to disagree with statements indicating that the primary value of mathematics lies in following directions, and that the language of mathematics is excessively rigid (see Figure 7).

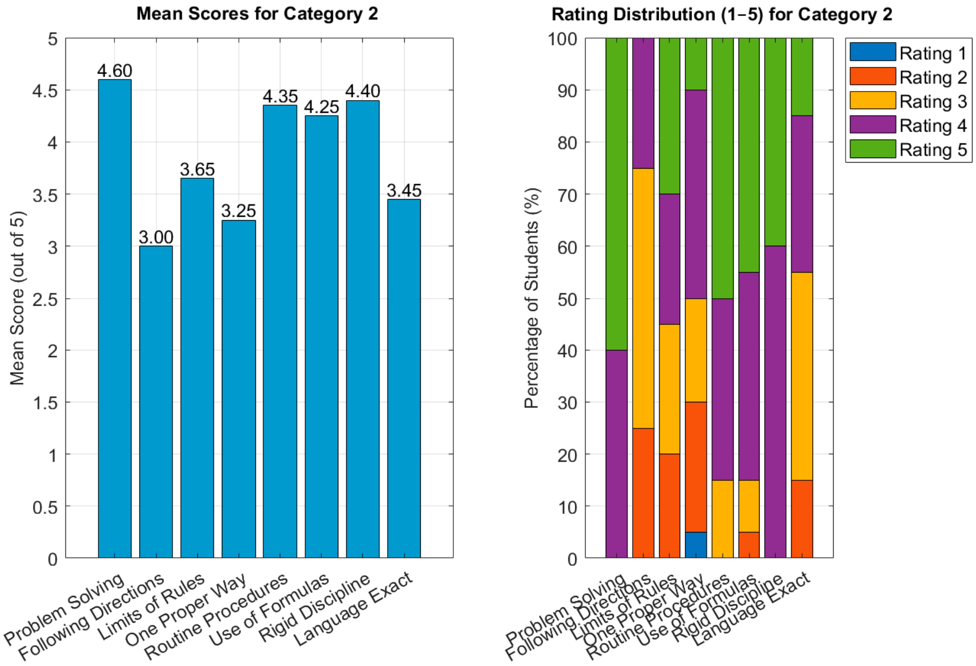

Figure 7. Mean and percentage rating distribution of Category 2 statements in the mathematics belief survey.

Finally, Category 3 examined students' beliefs about the professional or societal role of mathematics and its importance. The statements in this category were divided into two sub-categories. The first sub-category focused on the applications of mathematics and outcomes of mathematical work. In this area, students expressed strong agreement, with 75% affirming that mathematics has produced many of the finest and elegant creations of humanity and has broad applications. Only 5% of students disagreed with these statements, reflecting high appreciation for the relevance and impact of mathematics. In contrast, the second sub-category explored student beliefs about the profession of mathematicians and the use and prospects of mathematics in the workplace. In this sub-category, the results were more mixed: 42% of students agreed that mathematicians are hired to make calculations for scientists, and many of these tasks are increasingly being taken over by computers; approximately 20% of students disagreed with these views (see Figure 8).

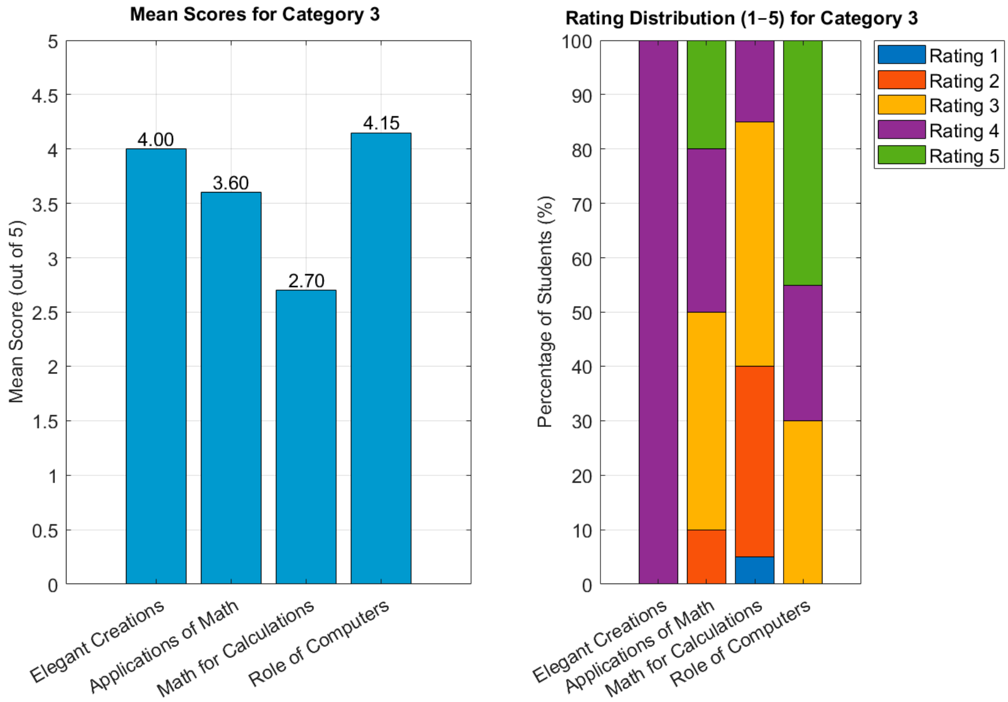

Figure 8. Mean and percentage rating distribution of Category 3 statements in the mathematics belief survey.

4.2. Flipped-Classroom Survey Results

The interactive nature of the sessions delivered through the flipped-classroom model, featuring teacher guidance, peer collaboration, and group discussions, marked a substantial shift from the passive traditional tutorial format. Findings from the learning rating survey indicate a positive progression in students' understanding of mathematical concepts. This improvement is attributed to the increased engagement facilitated by the interactive teaching strategies characteristic of the flipped-classroom approach. The ratings were collected on a five-point scale, ranging from 1 (Low or Poor) to 5 (High or Excellent). Table A3 shows the questions on the questionnaire, while Table 3 below summarizes the overall average student ratings across 10 flipped-classroom sessions for confidence, competence, and knowledge at the stages of before, middle, and after each session.

Table 3. Student ratings overall average from the semester survey in teaching class sessions.

	Overall Average Before (KB)	Overall Average Middle (KM)	Overall Average After (KA)
Confidence	1.58	2.71	4.03
Competence	1.51	2.81	3.94
Knowledge	1.52	2.68	4.06

4.3. Statistical Analysis of Flipped-Classroom Survey Ratings

As presented in Table 4, the results of the statistical analysis yielded p-values below the threshold of 0.05, allowing us to confidently reject the null hypothesis. These findings confirm that there are statistically significant differences in student ratings of confidence, competence, and knowledge progression across the learning sessions. Wilcoxon's Signed-Rank Test further supported these results, with a lower p-value reinforcing the significance of the observed changes. These outcomes also coincide with the box plots shown in Figure 9, which visually depict an upward trend in knowledge ratings through the progress of the learning sessions in the flipped classroom.

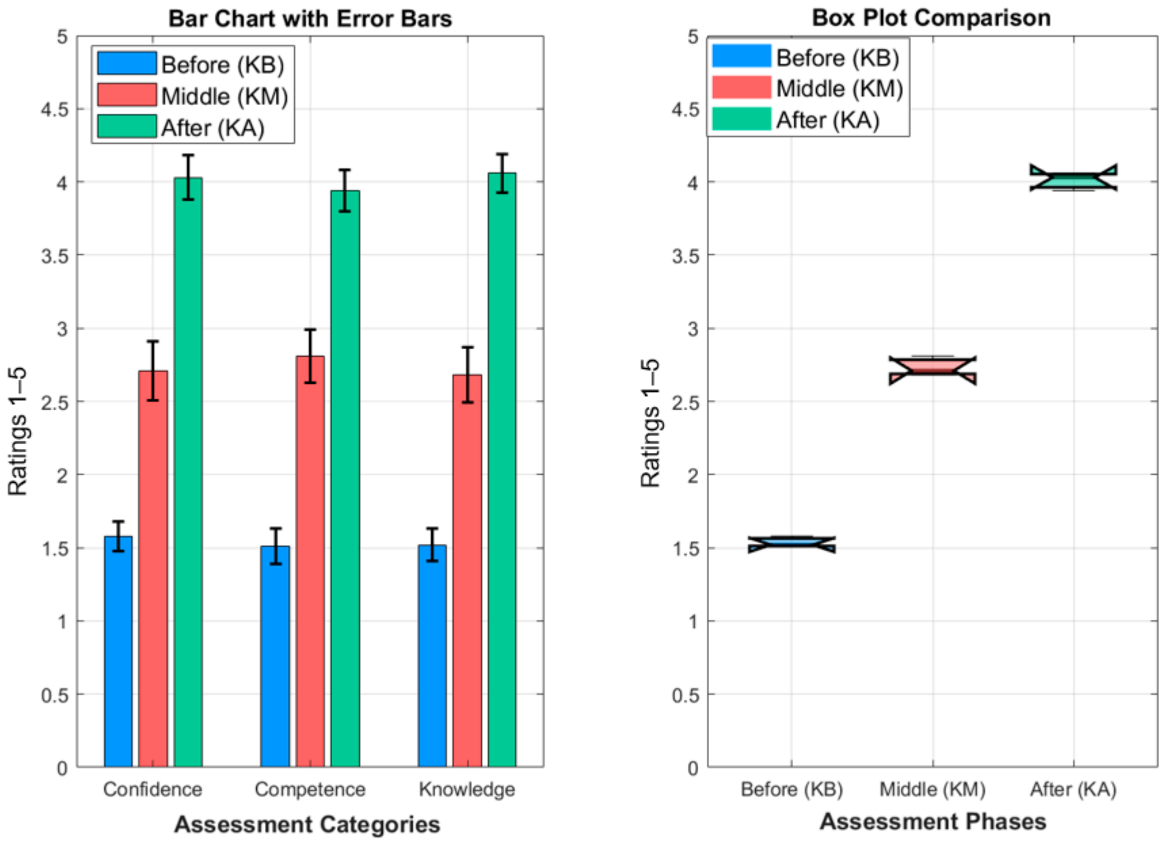

Figure 9. Box plot of average confidence, competence, and knowledge ratings during the class sessions in flipped classroom.

Table 4. Friedman's and Wilcoxon's test results for confidence, competence, and knowledge ratings.

Confidence Analysis Results	Competence Analysis Results	Knowledge Analysis Results
Friedman's test statistic: 59.0, *p*-value: 0	Friedman's test statistic: 60.5, *p*-value: 0	Friedman's test statistic: 60.6, *p*-value: 0
Significant difference (CFA, CFM, CFA)	Significant difference (CPA, CPM, CPA)	Significant difference (KB, KM, KA)
Wilcoxon's Signed-Rank Test	Wilcoxon's Signed-Rank Test	Wilcoxon's Signed-Rank Test
Before vs. Mid: $p = 0.0000005319$	Before vs. Mid: $p = 0.0000005682$	Before vs. Mid: $p = 0.0000000009$
Before vs. After: $p = 0.0000010371$	Before vs. After: $p = 0.0000000009$	Before vs. After: $p = 0.0000000009$
Mid vs. After: $p = 0.0000011325$	Mid vs. After: $p = 0.0000005319$	Mid vs. After: $p = 0.0000020929$
Significant difference between Before and Mid.	Significant difference between Before and Mid.	Significant difference between Before and Mid.
Significant difference between Before and After.	Significant difference between Before and After.	Significant difference between Before and After.
Significant difference between Mid and After.	Significant difference between Mid and After.	Significant difference between Mid and After.

4.4. Qualitative Results

Figure 10 presents four significant dimensions of instructional delivery that emerged from the analysis of qualitative data. These dimensions include the following: (1) teaching methodologies and strategies; (2) the complexity and presentation of content; (3) levels of student engagement and learning outcomes; and (4) challenges specific to the flipped-classroom model. The codes were used to zoom in on the "tensions" occurring within and between the activities under the activity theory framework (Engeström, 2014b). The coding process was guided by the activity theory framework (Engeström, 2014b) allowing for a focused examination of the "tension" occurring both within and between activity systems.

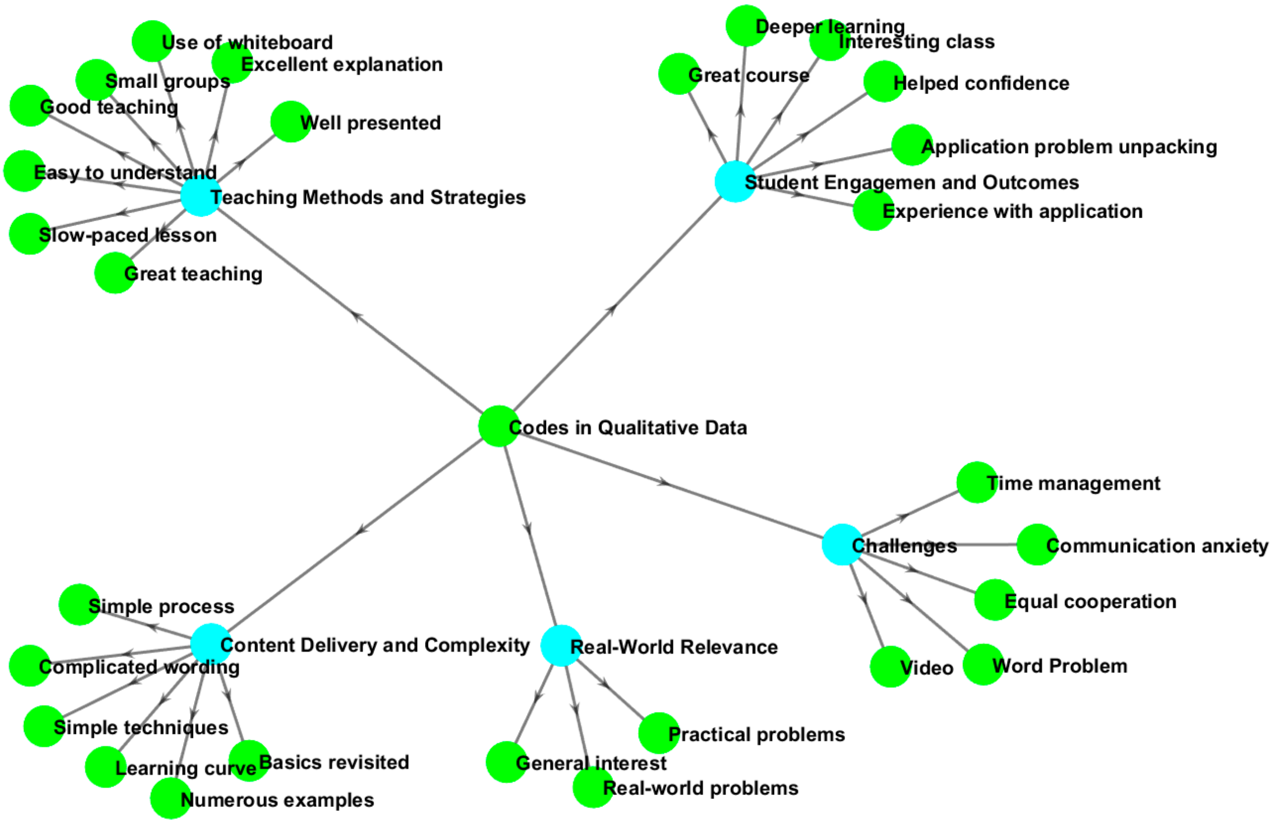

Figure 10. Conceptual code graph showing keywords from the qualitative analysis.

4.5. Contradictions ("Tensions") Analysis

Analysis of qualitative data with a focus on contradictions involves a "zoom-in" approach, which allows for a detailed examination of specific interactions within the activity system. Murphy and Rodriguez-Manzanares (2008) emphasize this technique in their exploration of contradictions in educational technology. Similarly, Barab et al. (2002) used the process of zooming or a narrow lens to investigate the relationship between participants and the object of activity systems. This study adopts a comparable methodological approach, positioning the first-year student as both the central subject and the primary agent interacting with the various components of the activity system. To rigorously move from symptoms to the identification of contradictions, this study utilized Engeström and Sannino's (Engeström, 2014b; Engeström & Sannino, 2011) methodological framework by using their taxonomy of dilemmas, conflicts, critical conflicts, and double binds as heuristic tools to categorize and interpret the discursive manifestations of contradictions. At the basic level, these can be seen as a dilemma where students are caught between learning only the fundamental concepts and being required to engage with advanced content that they perceive as irrelevant. Although there is a presence of incompatibility, the situation is still negotiable. Conflict is a disagreement between expectations and curriculum goals. However, it is yet to be escalated as an active struggle. If the contradiction is deeply rooted, it can be characterized as a critical conflict, indicating a systemic and structural issue that can lead to resistance or disengagement. A double bind is a situation where contradictory demand is placed on the students, and they see that satisfying one violates the other. Following this taxonomy, contradictions were identified, as follows:

1. Student Expectation–Curriculum Structure: The student sees a contradiction between engineering mathematics as a core or service course, whereby it is only for learning basic concepts, and advanced concepts with complex problem-solving are not of value in their program of study. The "tension" is in the exchange value of the core subject for the engineering program.
   "At first, I thought why do we need to these high-level problems when we will not use all of these in our engineering courses? I am doing surveying, I could understand it is interesting to see all the real-life examples, but I thought I might only use Trigonometry. Was wrong as teacher showed the connections with the topics and concepts".
2. Old and New Delivery System: The shift from passive learning to an active, interactive flipped classroom causes "tension" with students' learning habits. Some students find it challenging with the transition in teaching delivery.
   "Given I have to cover the basics beforehand and then come to discuss concepts in class is new for me and I will need time to adjust to this. I am more use to taking in information in class and then work on my own. I must admit I did find myself lost sometimes being alone in the old style while I can share and talk more in this way".
3. Motivation and Anxiety: Students are motivated by application and real-life problem-solving but their communication and mathematics-related anxiety holds them from freely participating in the interactive sessions.
   "I like solving problems, but I always had an anxiety for mathematics and think I might ask silly questions or ask little things that everyone knows and embarrass myself. This however got a lot better after few sessions and now I do feel confident to share and discuss".
4. Self-Regulated Learning and Accountability: Prior completion of watching videos and other resources by students is a matter of self-regulation and accountability. It can be overwhelming for students with a high content load. Lack of immediate feedback and poor time management can lead to disengagement and frustration.
   "As a working student, finding time is an issue with me and when I cannot understand something, I need to ask to know which I cannot do while watching the video. I might or not watch the rest but not get the concepts. This is where I found supporting resources and links extremely helpful".
5. Learner Pace and Group Interactive Learning: The pace of learning in an interactive group setting is an important issue as some students can tend to lag if the other students are working at a faster pace than them when discussing and solving problems.
   "I sometimes feel that I am much slower in understanding to solve some problems and the group works faster, and I do not want to hold others back, but it becomes challenging for me as I take more time with some topics such as logarithms and exponentials for example which is very new to me, I may have forgotten the basics to be honest. I found talking to the tutor really helped in between to stitch the gaps".

4.6. Recommendations

As previously noted, "tensions" can become a catalyst for expansive learning (Engeström, 2014a). The importance of core courses, particularly mathematics within engineering programs, should be explicitly embedded in the introductory components of all relevant courses. The educators of first-year courses play a critical role in ensuring that the students understand the linkage of course learning outcomes that align with broader program-level outcomes. The foundational principles covered in the first-year mathematics course should be framed as interrelated themes rather than isolated topics. This approach fosters a comprehensive understanding of how different topics support and build upon one another (Erickson et al., 2009). For example, mastering trigonometry requires prior knowledge of algebra, geometry, and the concepts of relations and functions. Presenting these connections helps students see the coherence in their learning and reduces cognitive fragmentation. More challenging first-year concepts such as kinematics require knowledge from algebra and functions to solve linear and quadratic equations. A connected diagrammatic schema illustrating the patterns and dependencies between concepts will help the learner to understand and solve the problems better.

The study results show an increase in the confidence rating among students, which emphasizes the importance of the affective domain in the flipped classroom approach. A study involving science students in higher education found that the use of a flipped-classroom approach also showed a positive impact on students' emotions and perceptions, particularly among those without a prior science background (Jeong et al., 2021). Hence, students must develop a sense of belonging within the classroom and feel that making mistakes and asking questions are an integral part of a learning journey. This can be achieved through peer-to-peer experience sharing sessions in the group setting, promoting a growth mindset towards learning (Gamlath, 2022). For example, before starting the calculus topic, students could work together in small groups to collaboratively write a reflection on their perspectives about the relevance and applications of calculus in real life. This activity will encourage them to connect prior knowledge with new concepts and fosters engagement by highlighting calculus's practical importance through discussion. Collaboration can be facilitated through working together on rich open-ended problems to find more than one way to solve a mathematics problem (Chan & Clarke, 2017). Working in groups using online digital tools such as Desmos Classroom, GeoGebra, and Padlet is very useful to promote synchronous collaboration (Tesfamicael, 2022).

To enhance engagement before classroom sessions, pre-engagement resources, such as videos, should be designed creatively, incorporating self-assessment tools and interactive elements. For instance, platforms like H5P and Panopto enable the integration of quiz questions, notes, captions, and nudging links alongside the video content. For example, Panopto quizzes on algebraic solving can be embedded to cover topics like addition, subtraction, multiplication, and division, providing students with immediate practice and feedback within the video lesson. These features allow students to check their understanding in real-time and keep them actively involved in their learning. Maintaining accountability is essential in a flipped-classroom model. This can be supported using learning management systems such as Moodle, which allows educators to attach badges and completion trackers to specific learning tasks. For example, Moodle provides the capability to award badges upon the successful completion of specific tasks, including the viewing of instructional videos. Furthermore, Panopto offers the functionality to download student responses to quizzes that are integrated within these videos.

4.7. Limitations of This Study

There are some limitations to this study that should be acknowledged. The primary limitation is the small sample size of participants, comprising only 20 participants, which is below the commonly recommended minimum of 30 for many statistical analyses. Hence, nonparametric tests were employed to analyze the data in this study. This may impact the statistical power of the results and increase the likelihood of Type II errors, potentially leading to overlooked significant effects. Additionally, the research was conducted within a single institution or department, characterized by specific teaching practices and student demographics. As a result, the generalizability of the findings to other educational contexts may be limited. Furthermore, data collection relied on self-reported measures of student engagement and satisfaction through surveys and reflective responses. These measures may be subject to response bias as students might provide favorable responses due to novelty effects or perceived expectations. Lastly, the effectiveness of the flipped-classroom approach may have been influenced by the individual teaching style or experience of the instructor involved.

5. Conclusions

Core mathematics courses are foundational to academic success for engineering students in higher education. These courses play a pivotal role in ensuring students acquire the essential skills and conceptual knowledge needed to excel in their respective fields of study. However, first-year engineering mathematics often presents significant challenges. These difficulties stem from a range of factors, including insufficient academic preparation, mathematics-related anxiety, and a limited ability to connect theoretical content to real-world applications. The transition from secondary to tertiary mathematics remains a critical area of inquiry, with ongoing debate around the most effective pedagogical strategies for delivering engineering mathematics.

This study employed a belief survey to assess general student attitudes toward mathematics among first-year students. It utilized the activity theory framework to conduct an in-depth exploration of the experiences of first-year engineering students and to identify the contradictions, or "tensions," they encounter within a flipped-classroom instructional model. Quantitative data were collected through surveys measuring changes in student confidence, competence, and knowledge acquisition. The analysis, based on Friedman's and Wilcoxon's Signed-Rank Tests applied to data from 20 participants across 10 flipped-classroom sessions, revealed statistically significant improvements in all three areas. This will support a more seamless transition to a wider group in research in the future. Specifically, all of Friedman's test statistics exceeded 50, with p-values below 0.05, indicating notable progress. The findings were further supported by Wilcoxon's Signed-Rank Test, which also yielded a p-value below 0.05, allowing for the rejection of the null hypothesis. Qualitative insights were obtained from student responses to open-ended survey questions and one-to-one interviews. These data revealed several key findings that illuminated critical aspects of the flipped-classroom model, highlighting emerging contradictions ("tensions") that stimulate "expansive learning." These included the following: misalignments between student expectations and the curriculum structure, tensions between traditional and contemporary teaching approaches, challenges with self-regulation and accountability, disparity in the group learning pace, and the dual influence of motivation and anxiety. Understanding these dynamics is crucial for educators and academic stakeholders involved in the design and delivery of first-year mathematics curricula.

The findings suggest that the flipped-classroom model enhances student engagement and knowledge acquisition through its emphasis on active student-centered learning. However, for this instructional approach to be more effective, it is essential to address the identified challenges. The challenges can be unequal access to technology, cognitive overload or confusion, low pre-class participation, teacher preparation and training, time and workload (for students and teachers), classroom management in group work, assessment alignment, and resistance to change. The flipped model helps shift focus from passive notetaking to active problem-solving, collaboration, and discussion. Students gain a deeper understanding through in-class application and group participation in a flipped environment. Institutions need to support active, student-centered learning models in foundational courses. This supports the importance of gaining deeper conceptual understanding and provides a platform for teaching engineering mathematics in a more flexible way. Traditional assessments may not align with the flipped classroom's focus on problem-solving, reasoning, and collaboration; therefore, updating requires integrating formative and performance-based assessments. There will be a need for curriculum developers to rethink assessments for effective student learning goals. This will support a more seamless transition for students entering their first year and, ultimately, contribute to improved retention and success in engineering programs. This study can be expanded to further explore the experiences of different modes of learning in future research.

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Appendix A

Table A1. Belief survey questions to investigate students' views on various aspects of mathematics. The questions were categorized as follows: Category 1—creativity and flexibility in mathematics (creative thinking and interpretation, originality, multiple methods). Category 2—rules, procedures, and structure in mathematics (fixed laws, formulas, routines). Category 3—professional or societal role of mathematics (the importance and use of mathematics in context).

Category	Survey Questions
2	Solving a mathematics problem usually involves finding a rule or formula that applies.
3	The field of math contains many of the finest and most elegant creations of the human mind.
2	The main benefit of studying mathematics is developing the ability to follow directions.
2	The laws and rules of mathematics severely limit how problems can be solved.
1	Studying mathematics helps to develop the ability to think more creatively.
1	The basic ingredient for success in mathematics is an inquiring nature.
1	There are several different but appropriate ways to organise the basic ideas in mathematics.
2	In mathematics, there is usually just one proper way to do something.
2	In mathematics, perhaps more than in other fields, one can find set routines and procedures.
3	Mathematics has so many applications because its models can be interpreted in so many ways.
3	Mathematicians are hired mainly to make precise measurements and calculations for scientists.
1	In mathematics, perhaps more than in other areas, one can display originality and ingenuity.
1	There are several different but logically acceptable ways to define most terms in math.
2	Math is an organized body of knowledge that stresses the use of formulas to solve problems.
1	Trial-and-error and other seemingly haphazard methods are often necessary for mathematics.
2	Mathematics is a rigid discipline that functions strictly according to inescapable laws.
3	Many of the important functions of the mathematician are being taken over by the new computers.
1	Mathematics requires very much independent and original thinking.
1	There are often many ways to solve a mathematics problem.
2	The language of math is so exact that there is no room for a variety of expressions.

Table A2. General questions asked during the interview.

Questions
Subject: (First-Year Engineering Mathematics student)
What aspects of university transition is most challenging for Engineering Mathematics?
Will you be able to apply the knowledge to other problems on the same concept?
Do you have any background knowledge of the concepts?
Did your previous learning prepare you well for this course?
What obstacles do you see when solving the Maths problem(s)?
What are the "mental blocks" that hinder you to understand mathematical problems?
Objective (Learning Mathematics concepts for Engineering)
How important do you think learning mathematics concept are for your Engineering program?
Do you think this mathematics topics in this course will contribute to better understanding of other Engineering concepts?
Tools (Mediation)
Do you use any mathematical software or online tools or other online videos to understand mathematical concepts? How does it help you to learn the concepts?
Do you enjoy group work and interactive learning session in the flipped-classroom mode? Please explain why you do or do not?
What ENM1500 study desk resources do you rely on to help you with learning mathematical concepts?
Do you know how to use your scientific calculator to help in calculations?
Did you seek support from mathematics learning advisors, transition coordinators, and peer leaders at UniSQ?
Rules
Are you familiar with assessment policies and technical mathematical communication in ENM1500?
Community
Do you communicate with your peers in the course?
Do you feel a sense of belonging in the flipped-classroom class? Please explain.
Have you scheduled consultations with your lecturer or tutor when you needed help?
Division of Labor
Do you watch the recorded video on the study desk before coming to class?
Do you work on your assessment tasks every week as concepts is covered or do you do everything before the due date at once?
Have you made a timetable for your study for the semester?
Outcomes
What improvements can make to better cope with your study?
Are you using your same learning habit from your past learning before tertiary study or changed your approach?

Table A3. Course session survey questions given during the workshops of ENM1500.

Part 1: Please rate the following criteria. 1 means Low or Poor; 5 means High or Excellent	**1**	**2**	**3**	**4**	**5**
My knowledge of the concepts **BEFORE** this session.	☹	☹	😐	☺	☺
My confidence level of the concepts **BEFORE** this session.	☹	☹	😐	☺	☺
My competence level of the concepts **BEFORE** this session.	☹	☹	😐	☺	☺
My knowledge of the course concepts **MID session.**	☹	☹	😐	☺	☺
My confidence level of the course concepts **MID session.**	☹	☹	😐	☺	☺
My competence level of the course concepts **MID session.**	☹	☹	😐	☺	☺
My knowledge of the concepts **AFTER** this session.	☹	☹	😐	☺	☺
My confidence level of the concepts **AFTER** this session.	☹	☹	😐	☺	☺
My competence level of the concepts **AFTER** this session.	☹	☹	😐	☺	☺
The knowledge and skills learned are relevant to my studies.	☹	☹	😐	☺	☺

Part 2: Comments

1. What did you most like about this session?
2. How did the session help you to overcome the obstacles you had with the concepts?
3. Do you have any other comments?

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