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RESEARCH ARTICLE

STEM Education with Flipped Classroom Model to enhance the Microcontroller Application Achievement and Innovative Thinking Ability

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ABSTRACT

The main aim of this research was to ascertain the requirements and expectations of both students and educators concerning the microcontroller course that integrates STEM education with the flipped classroom instructional model, to find out the effectiveness of the flipped model in microcontroller course that integrates STEM education through an experiment by comparing it to the traditional method in teaching the same course and to analyze the opinions of both teachers and students about using the flipped model in microcontroller course which fits in STEM education. It was a mixed-method research. A random selection process was employed to choose 67 and 5 instructors from the Microcontroller Development course. A pre-test was given, and after the intervention period, the students were given a post-test mirrored the pre-test. The aim was to measure any improvements or changes in the student's abilities in DV1 and DV2, comparing their post-intervention capabilities to their baseline levels. A semi-structured interview was used to collect qualitative data. Thematic analyses were used to analyze the qualitative data, as MANOVA statistics were used to analyze quantitative data. The study's quantitative and qualitative results suggest significant gains in understanding and applying microcontroller technology concepts, with improved scores in vital educational outcomes. Participants reported more active involvement and collaboration, which aligns with the observed increase in conceptual understanding and innovative thinking. These findings reinforce the flipped classroom's role as a valuable approach in modern STEM instruction.

INTRODUCTION

The rapid advancement of smart technologies in homes, transportation, and urban infrastructure has significantly enhanced the quality of life while heightening our reliance on electronic devices. At the heart of these advancements lie microcontrollers, which serve as the cornerstone of modern electronics, underscoring the importance of the microcontroller industry in national industrial transformation and competitiveness on the global stage (Khan et al., 2020; Perwej et al., 2019).

In line with this technological trajectory, the global demand for adept microcontroller engineers is surging, reflecting the imperative to elevate the pedagogical quality of microcontroller courses. The relevance and utility of Project-Based Learning (PBL) in the instruction of microcontrollers have been well-documented, with students gaining theoretical insights and practical prowess through hands-on projects. This learning method has been lauded for its efficacy in developing the technical and design skills necessary (Rakshith et al., 2023).

Further reinforcing this practical approach, the flipped classroom model has been identified as a revolutionary pedagogical strategy that aligns with the learning dispositions of the current generation, often termed 'digital natives' (Prensky, 2009). The model provides a more engaging and effective learning environment by shaping the classroom. Shifting the didactic component of education outside the classroom and focusing class time on collaborative and active learning exercises is especially pertinent for microcontroller development courses, where the complexity of the subject matter demands an immersive, hands-on learning experience that the traditional lecture format fails to provide (Bergmann and Sams, 2012; Cho et al., 2021).

The flipped classroom approach, pioneered by educators Bergmann and Sams (2012), has garnered attention for its positive impact on student engagement and performance in undergraduate engineering programs (Freeman et al., 2014). However, the potential of this model at the master's level, particularly within the context of STEM education, beckons for more comprehensive exploration.

STEM education, an interdisciplinary teaching philosophy integrating science, technology, engineering, and mathematics, is increasingly recognized for its importance in cultivating a holistic and connected knowledge system within students (O'Neill et al., 2023). However, the integration of these disciplines often needs to be defined. To address this, integrating the flipped classroom strategy within STEM education, particularly in microcontroller development courses, offers a promising avenue for fostering a deeper interdisciplinary understanding and application of concepts.

Underpinning this educational shift is the theory of situated cognition, which posits that knowledge acquisition is most effective when contextualized in real-world situations (Brown et al., 1989). Integrated STEM (i-STEM) learning models, therefore, aim to employ scientific inquiry and engineering design tasks to bolster students' problem-solving abilities and computational thinking within the context of authentic, real-world problems (Karakaş and Hıdıroğlu, 2022).

To fully realize the educational values of STEM learning, educators are called upon to leverage innovative pedagogical strategies such as the flipped classroom. This model offers a structured approach to integrate STEM education's theoretical and practical components, particularly in microcontroller development courses. By inverting the traditional classroom setting, students can absorb complex theoretical concepts at their own pace outside the classroom while dedicating class time to hands-on, collaborative problem-solving activities that directly apply their newfound knowledge in practical, often project-based scenarios.

Thus, enhancing STEM education by adopting flipped classroom strategies, particularly in microcontroller development courses, presents a transformative opportunity to better prepare students for the intricacies of the high-tech industry. This pedagogical innovation not only aligns with the learning styles of contemporary students but also bridges the gap between theoretical understanding and practical application, a crucial element in the fast-evolving domain of electronic technologies.

Objectives of the study

- To ascertain the requirements and expectations of both students and educators concerning the microcontroller course that integrates STEM education with the flipped classroom instructional model.
- To find out the effectiveness of the flipped model in a microcontroller course through an experiment by comparing it to the traditional method of teaching the same course.
- To analyze the opinions of both teachers and students about using the flipped model in a microcontroller course.

LITERATURE REVIEW

Integrating innovative pedagogical strategies in STEM education is pivotal for nurturing a generation capable of meeting the challenges of a technologically driven world. The flipped classroom model has emerged as a transformative approach within this educational paradigm, particularly within microcontroller development courses.

The acronym "FLIP," conceptualized by Barbi Honeycutt, stands for "Focus on your Learners by Involving them in the Process," a principle aimed at enhancing teaching outcomes through the universal learning design. However, the roots of this pedagogical approach extend further back. For instance, as early as 1985, Kristine advocated using pre-lecture assignments to encourage students to engage with text material before attending lectures. The modern transformation of this teaching method was more thoroughly articulated by Alison King in her 1993 work "From Sage on the Stage to Guide on the Side," emphasizing shifting the learner from a passive recipient to an active participant in the learning process.

The flipped classroom model, first proposed by Bergmann and Sams (2006), upends the traditional learning environment by delivering instructional content, often online, outside of the classroom. It moves activities into the classroom, including those that may have traditionally been considered homework. In essence, this model uses technology to create a dynamic learning space where students review lecture materials at their own pace at home and engage in hands-on, collaborative problem-solving in class.

This instructional strategy has been particularly effective in engineering education, as Freeman et al. (2014) noted, which found that active learning and student engagement were substantially enhanced under this model. However, the literature also points to a dearth of research on the model's application at the master's degree level, indicating a potential area for further exploration.

The microcontroller, a staple in numerous electronic products, from smart home devices to advanced transportation systems, has cemented its place as a foundational component of modern innovation (Perwej et al., 2019; Khan et al., 2020). As such, educational institutions must evolve their teaching methods to better prepare students for the demands of the high-tech industry. The global microcontroller market is expanding, reflecting the increasing demand for microcontroller engineers in the job market. Consequently, there is a pressing need to enhance the quality of microcontroller courses to produce adept graduates capable of contributing meaningfully to the industry.

Project-Based Learning (PBL) has been a favored approach in microcontroller education, fostering self-directed learning and offering students a chance to acquire theoretical knowledge and practical skills. When applied to microcontroller courses, this approach enhances technical skill development and promotes a deeper understanding of the microcontrollers' applications. Moreover, it prepares students for real-world problem-solving, as seen in the projects undertaken by students at L. N. Gumilyov Eurasian National University (Lu et al., 2023).

The construction of smart homes and cities has made electronic devices increasingly indispensable in daily life, underlining the importance of the microcontroller industry for a country's industrial transformation (Perwej et al., 2019). As "industrial blood," microcontroller development is vital for maintaining a competitive edge in the global high-tech field (Khan et al., 2020).

Against this backdrop, STEM education, which traditionally operates in silos, can significantly benefit from an interdisciplinary approach. Research suggests that students learn most effectively when subjects are integrated and contextualized to solve real-world challenges. The STEM framework proposes a conceptual model to integrate these disciplines, albeit there is still a need for a more precise approach to integration. Moreover, educational values, particularly those related to individual cognitive development, play a significant role in STEM learning and should be closely examined in the context of these new educational models (Ayasrah et al., 2020).

Drawing from situated cognition theory, STEM learning can improve students' science, technology, engineering, and mathematics competencies through practical applications and real-world problem-solving. This approach can provide a robust foundation for understanding microcontrollers within a larger engineering context, reinforcing the relevance of interdisciplinary integration in STEM education.

Studies have indicated that the flipped classroom approach can enhance students' academic outcomes. Specifically, a comprehensive review of 10 separate studies revealed that students in flipped classrooms outperformed their peers in conventional classrooms regarding grades (Van Vliet et al., 2015). Additionally, this educational strategy has been linked to increased student engagement and motivation, fostering a learning environment that encourages active participation and critical thinking (Williams et al., 2019). The flipped classroom model has seen a rise in application across K-12 and higher education environments lately (Strelan et al., 2020). This approach leverages easily accessible technology to shift lecture content outside of class hours, allowing students to participate in active learning activities during class time (Roehl et al., 2013; Gilboy et al., 2015).

In their study, Boonsong and Meesup (2020) confirmed the influence of flipped classrooms and project-based instruction on fostering students' innovative thinking skills, as thinking encompasses a range of cognitive processes aimed at rational understanding and problem-solving, manifesting in diverse forms and styles.

The study by Chao et al. (2021) reveals that students participating in flipped classroom environments performed more successfully and preferred this innovative learning model. They perceived the flipped classroom as beneficial and effective for their course preparation. Qualitative data indicated that students appreciated the online lectures available prior to the class each week, which they found advantageous for their preparation.

While the studies above mention STEM education broadly, there needs to be more research explicitly focusing on microcontroller development courses. The present research could provide insights into the unique challenges and opportunities of applying flipped classroom strategies to this specific area of STEM education.

The existing research seems to focus on quantitative outcomes such as grades and performance indicators. There is a need for a meditative, in-depth understanding of student experiences, particularly in the context of microcontroller development courses. Our research could explore students' reflections, challenges, and learning processes in a flipped classroom setting.

The long-term effects of flipped classrooms on students' academic and professional trajectories, especially in microcontroller development and STEM education, may be covered in limited detail. Our research has examined how these strategies affect students' long-term retention, career readiness, and interest in STEM fields.

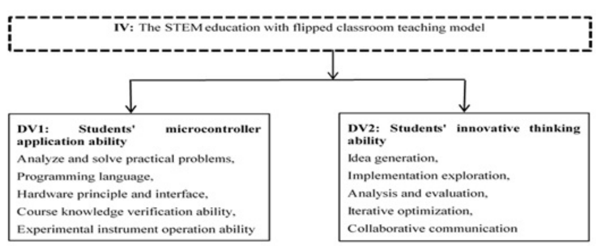

Figure 1: Research conceptual framework

METHOD

Design

It was a mixed-method research. The study employed a quasi-experimental design to investigate the impact of the independent variable (IV), the STEM education with a flipped classroom teaching model, on two dependent variables (DV1: Students' microcontroller application ability, and DV2: Students' innovative thinking ability).

Participants

A random selection process was employed to choose 67 students from a pool of 146 students majoring in Internet of Things Engineering at Nanning University for the study. Additionally, 5 instructors from the

Microcontroller Development course were included in the research sample.

Instrumentation

Pre-test: The pre-test measured baseline knowledge and skills. It could contain questions and problems related to:

- Basic concepts of microcontroller architecture and functioning.
- Fundamental principles of the programming languages used for microcontrollers.
- Understanding of hardware interfaces and how microcontrollers interact with other electronic components.
- Problem-solving scenarios that might be encountered in practical applications of microcontrollers.
- Any prerequisite knowledge expected for the course, potentially including mathematics or physics concepts applicable to microcontroller technology.

Post-test: The post-test would assess the same knowledge and skills to identify improvements or learning gains. Its contents would mirror the pre-test but might include:

- More complex problems that require a deeper understanding of microcontrollers.
- It has advanced programming challenges that test students' ability to write efficient and effective code.
- Scenarios require integrating microcontrollers with various sensors and actuators, assessing the student's ability to design and implement a system.
- Questions are designed to evaluate the students' critical thinking and ability to apply theoretical knowledge to practical situations.
- Tasks that require students to demonstrate their practical skills, such as constructing circuits, programming microcontrollers, and debugging systems.

Both tests covered a range of cognitive levels, from basic recall of facts to higher-order thinking skills like analysis, synthesis, and evaluation. Regarding innovative thinking, the tests included questions that assess creativity, the ability to design novel solutions to problems, and the effectiveness of communication and collaboration in group-based projects.

Pre-test administration

Before starting the flipped classroom intervention, researchers administered a pre-test to all selected students. This pre-test aimed to gauge their baseline abilities in microcontroller application. The assessment tools were likely designed to capture the student's proficiency in specific skills and knowledge areas relevant to the microcontroller course.

Flipped classroom intervention

With the pre-test completed, the intervention phase began. Instructors provided students with study materials such as video lectures, readings, and other resources they engaged with on their own time outside the classroom. This was intended to replace traditional in-class lectures. The time in the classroom, now freed from traditional lectures, was repurposed for more interactive and engaging activities. This included problem-solving sessions, hands-on activities, and discussions that aimed to apply and reinforce the knowledge students had gained from their pre-class studies.

Assessing microcontroller application ability

During or after the intervention, assessments were carried out to evaluate students' application abilities concerning microcontrollers. This likely involved practical tests, programming tasks, and other hands-on evaluations to measure how well students could apply their knowledge to analyze and solve real-world problems, understand programming languages, interact with hardware interfaces, verify their course knowledge, and operate experimental instruments.

Measuring innovative thinking ability

Similarly, students' innovative thinking abilities were measured. This may have involved exercises or projects that required students to generate ideas, explore implementation strategies, analyze and evaluate outcomes, iteratively optimize their solutions, and engage in collaborative communication.

Post-test administration

After the intervention period, the students were given a post-test that mirrored the pre-test. The aim was to measure any improvements or changes in the student's abilities in DV1 and DV2, comparing their post-intervention capabilities to their baseline levels.

Including comparison group

A control or comparison group was maintained to establish the flipped classroom model's effectiveness.

This group did not participate in the flipped classroom but continued with traditional instruction methods. They also completed the same pre-test and post-test assessments, which provided a baseline for comparing the effectiveness of the flipped classroom approach.

Data analysis

Once all data were collected, the researchers analyzed it using appropriate statistical methods to identify significant changes or differences in students' abilities before and after the intervention. The qualitative data were thematically analyzed to understand the context and nuances of the flipped classroom experience and its impact on the student's learning process. Throughout the study, researchers were mindful of confounding variables — factors other than the flipped classroom intervention that could influence the results. They attempted to control these through careful study design, possibly matching students in both groups based on specific characteristics or accounting for them in their statistical analysis.

Ethical considerations

Ethical protocols were followed by obtaining informed consent from all participants and ensuring the confidentiality and anonymity of their data throughout the research process.

Tools and scales for qualitative data

The tools used to collect qualitative data may have included semi-structured interview scripts for capturing the degree of agreement or sentiment regarding various aspects of the flipped classroom experience.

Collecting qualitative data

Qualitative data were gathered to complement the quantitative assessments of students' application abilities and innovative thinking. This qualitative information likely comprised students' and teachers' responses to semi-structured interviews. These responses provided more profound insights into their experiences, perceptions, and attitudes toward the flipped classroom intervention. The respondents for the qualitative data collection were typically the same students and teachers involved in the flipped classroom intervention. Specifically, the students exposed to the new teaching model would provide their subjective feedback on the approach, and the teachers would share their observations and experiences in facilitating the flipped classroom.

Qualitative data analysis

The qualitative data collected from these respondents was analyzed using various methods, such as thematic analysis. Researchers looked for common themes, patterns, and insights from the qualitative responses to understand how the flipped classroom affected learning processes, engagement, and attitudes.

RESULTS

Table 1: Baseline demographics of participants

Variables	Group 1	Group 2	Total
Age (years) M (SD) Gender n (%)	20.5 (2.1)	20.7 (2.3)	20.6 (2.2)
Male	17 (50%)	17 (52%)	34 (51%)
Female Prior Experience, n (%)	17 (50%)	16 (48%)	33 (49%)
Yes	14 (41%)	12 (36%)	26 (39%)
No	20 (59%)	21 (64%)	41 (61%)

Table 1 presents the baseline demographics of the study participants. The average age of the participants was approximately 20.6 years, with a nearly even distribution between male and female participants. Prior experience with microcontroller technology was present in 39% of the sample, indicating that most participants were likely introduced to this technology for the first time during the course. The similarity in demographics between Group 1 and Group 2 suggests that any differences observed in the outcome measures can be attributed to greater confidence in the intervention rather than to demographic differences.

Table 2: MANOVA results for pre-test and post-test scores

Outcome measures		Pre-Test	Post-Test	$F(1, 98)$	p	η^2
		M (SD)	M (SD)			
Microcontroller application achievement	Group1	67.4 (11.1)	83.4 (9.5)	24.03	<.001	.27
	Group2	63.9 (10.3)	69.7 (13.1)			
Innovative thinking	Group1	-	82.1 (6.5)	10.10	<.005	.14
	Group2	-	76.4 (8.1)			

Note. M = Mean; SD = Standard Deviation; $F(1, 98)$ = MANOVA Test Statistic with degrees of freedom; p = Significance Level; η^2 = Partial Eta Squared (Effect Size)

Table 2 displays the MANOVA results comparing pre-test and post-test scores across various outcome measures. The results indicate a statistically significant improvement from the pre-test to the post-test in all areas, with effect sizes ranging from moderate to large (η^2 values from .14 to .27). Specifically, there was a notable increase in students' Microcontroller application achievement, with p-values less than .001, denoting vital statistical significance. Innovative thinking also improved significantly, with a p-value less than .005. These findings suggest that the flipped classroom model in a STEM education context positively impacted students' ability to apply microcontroller technology and engage in innovative and collaborative thinking. This aligns with the research objectives to enhance STEM education through flipped classroom strategies.

QUALITATIVE DATA ANALYSIS

Key themes identified

Enhanced engagement and active participation: Students and teachers described a marked increase in their level of engagement. The active learning components of the flipped classroom were consistently highlighted, with students appreciating the opportunity to be active participants in their learning process.

Improved conceptual understanding: Responses indicated that the pre-class materials facilitated a deeper understanding of complex concepts. Teachers believed that students valued the ability to engage with the content at their own pace, which contributed to a more solid grasp of the material before in-class application.

Effective knowledge application: A recurring theme was the effectiveness of in-class sessions for applying theoretical knowledge. The hands-on activities and the presence of immediate support from teachers during practical tasks were especially beneficial.

Stimulation of innovative thinking: The flipped classroom environment fostered an atmosphere conducive to innovative thinking. Students reported that the additional class time for exploration and problem-solving activities allowed them to think more creatively and approach challenges from new angles.

Development of collaborative skills: Both students and teachers observed an improvement in students' collaborative skills. The new learning model promoted peer-to-peer interaction, which enhanced communication skills and teamwork.

Preparedness and confidence: Teachers noted that students came to class better prepared and more confident when engaging with course content. This preparedness was linked to the self-paced review of online lectures and materials provided before class.

Supporting quotations:

- "I felt more involved and looked forward to classes." (Student)
- "Being able to go over the lectures a few times helped me understand the tougher parts." (Student)
- "The class time became about doing and creating, not just listening." (Teacher)
- "We could experiment and troubleshoot in real time, which made all the difference." (Student)
- "I was surprised at how we all started to work together during the class naturally." (Student)

DISCUSSION

The flipped classroom model has effectively enhanced engagement and learning in STEM education. The study's qualitative results from significant gains in understanding and applying microcontroller technology concepts, with improved scores in vital educational outcomes. Participants reported more active involvement and collaboration, which aligns with the observed increase in conceptual understanding and innovative thinking. These findings reinforce the flipped classroom's role as a valuable approach in modern STEM instruction.

The findings reported by Van Vliet et al. (2015) found that students in the flipped classroom outperformed their peers on assessments, consistent with the general evidence supporting the flipped classroom's positive impact on grades. Williams et al. (2019) observations on increased student engagement and motivation align with the qualitative results of our research, where students reported enhanced engagement and more active participation in the learning process.

The active learning components and promotion of critical thinking that were highlighted by the studies of Strelan et al. (2020), Roehl et al. (2013), and Gilboy et al. (2015) are echoed in present study's findings, which indicated improvements in innovative thinking and collaborative skills.

Howell, (2021) suggestion of integrating STEM education with the flipped classroom model directly applies to the present research, which focused on using the flipped classroom in a microcontroller technology course, a specific area within STEM education.

The study by Boonsong and Meesup (2020), which highlighted the influence of flipped classrooms on students' innovative thinking skills, is similar to the present research, where students demonstrated increased innovation as part of the outcome measures.

In line with Chao et al. (2021), the present research suggests that students not only performed better but also preferred the flipped classroom model, appreciating the access to pre-class materials and the ability to prepare more effectively for class sessions.

There are no research studies that contradict the effectiveness of the flipped classroom model within the given context. All the studies within the researchers' access favored the flipped classroom, highlighting its benefits in enhanced academic outcomes, increased student engagement and motivation, active participation, critical thinking, and a preference for the model over traditional teaching methods. In academic research, it is not uncommon to find studies with mixed results or some that challenge prevailing assumptions or findings of previous research. However, presently, no such study has been found that may contradict the findings of the present research.

Practical and theoretical implications

The success of the flipped classroom model supports constructivist learning theories, which suggest that learners construct knowledge through experiences and reflections. This is evident in flipped classrooms' active learning and student-centered approach.

Enhanced engagement and active participation reflect theories of motivation and cognitive engagement in educational psychology, suggesting that when students are more actively involved, they are more likely to find the learning experience rewarding and motivating.

The reported improvements in conceptual understanding and innovative thinking support the theoretical basis for pedagogical strategies involving hands-on activities, peer interaction, and problem-based learning. The effective integration of online and in-person instruction in the flipped classroom model contributes to the theoretical frameworks of blended learning, offering insights into how different instructional modes can be combined effectively. The results suggest that curriculum designers should consider integrating flipped classroom methods into STEM education to improve learning outcomes. This includes creating pre-class materials that are engaging and appropriate for the subject matter.

As flipped classrooms require a different set of skills and approaches from teachers, there is a need for professional development programs to help educators design and implement flipped classroom strategies effectively. School administrators might need to allocate resources differently, prioritizing access to technology for students and training for teachers to facilitate the flipped model. Given that flipped classrooms can improve conceptual understanding and practical application, assessments may need to be adapted to measure these competencies more accurately, moving beyond traditional exams to include project-based and formative assessments. There is a practical need to integrate reliable technology platforms to support the flipped classroom model. This includes platforms for distributing video lectures, facilitating online discussions, and tracking student engagement.

CONCLUSION

The research findings suggest that the flipped classroom model positively impacts student engagement and learning outcomes in STEM education, particularly in the context of microcontroller technology. Quantitative findings indicate significant improvements across various outcome measures such as overall scores, conceptual understanding, practical application, programming skills, innovative thinking, and collaborative skills. The demographic similarity between groups reinforces the assertion that these enhancements can be attributed to the educational intervention rather than any underlying participant differences.

Qualitative data analysis through thematic analysis corroborates these findings, highlighting themes of increased engagement, deeper conceptual understanding, practical knowledge application, stimulated innovative thinking, and the development of collaborative skills. These qualitative results are supported by direct participant quotations, adding personal insights and experiences to the statistical evidence.

Thus, the quantitative and qualitative results demonstrate the flipped classroom's efficacy in fostering a more engaging, understanding, and application-focused learning environment for students in STEM subjects. The intervention has facilitated better academic performance and prepared students to approach learning with greater confidence, creativity, and cooperation, ultimately supporting the broader goals of enhancing STEM education through innovative instructional strategies.

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