AKSIOMA: Jurnal Program Studi Pendidikan Matematika
Volume 15, No. 2, 2026, 1243-1255

ISSN 2089-8703 (Print)
ISSN 2442-5419 (Online)

DOI: https://doi.org/10.24127/ajpm.v15i2.14992

ENHANCING SELF-REGULATED LEARNING THROUGH A CULTURE-INTEGRATED STEM FLIPPED CLASSROOM APPROACH

Hairul Saleh[1*], Dian Nopitasari[2], Westi Bilda[3], Ahmad Fadillah[4]

[1,2,3,4] Universitas Muhammadiyah Tangerang, Tangerang, Indonesia
**Corresponding author: hairulumt@gmail.com*

Received 12 December 2025; Revised 05 May 2026; Accepted 27 June 2026

Abstract

This study was prompted by the challenge of low student autonomy in traditional education and the urgent need to foster self-regulated learning (SRL) through contextually relevant methods. It examined the effectiveness of a Culture-Integrated STEM–Flipped Classroom model in improving students' SRL. Using a quasi-experimental, pretest-posttest non-equivalent control group design, students from intact classes were assigned to an experimental group receiving the culture-integrated STEM–Flipped intervention and a control group receiving conventional instruction. SRL was measured before and after the intervention, and improvement was evaluated through gain score analysis. Results showed that the experimental group achieved a substantially higher gain (M=13.28) than the control group (M=5.44). The magnitude of the intervention effect, calculated using Cohen's d, was d=0.88, indicating a large effect. These findings demonstrate that integrating cultural values within a STEM-based flipped learning environment can significantly enhance students' ability to plan, monitor, and regulate their learning processes. The study concludes that combining culturally meaningful learning contexts with structured pre-class preparation and active in-class STEM problem solving provides a powerful approach for strengthening SRL.

Keywords: Flipped classroom; local culture; self-regulated learning; STEM education.

Abstrak

Penelitian ini didorong oleh tantangan rendahnya kemandirian siswa dalam pendidikan tradisional serta urgensi untuk menumbuhkan kemandirian belajar (SRL) melalui metode yang relevan secara kontekstual. Penelitian ini menguji efektivitas model Culture-Integrated STEM–Flipped Classroom (Kelas Terbalik Berbasis STEM Terintegrasi Budaya) dalam meningkatkan SRL siswa. Menggunakan desain kuasi-eksperimental jenis pretest-posttest non-equivalent control group design, siswa dari kelas yang sudah ada (intact classes) dibagi ke dalam kelompok eksperimen yang menerima intervensi STEM–Flipped terintegrasi budaya dan kelompok kontrol yang menerima pembelajaran konvensional. SRL diukur sebelum dan sesudah intervensi, dan peningkatannya dievaluasi melalui analisis gain score. Hasil penelitian menunjukkan bahwa kelompok eksperimen mencapai peningkatan yang secara substansial lebih tinggi (M=13,28) daripada kelompok kontrol (M=5,44). Besarnya efek intervensi, yang dihitung menggunakan Cohen's d, adalah d=0,88, yang menunjukkan efek yang besar. Temuan ini membuktikan bahwa pengintegrasian nilai-nilai budaya dalam lingkungan pembelajaran terbalik (flipped learning) berbasis STEM dapat secara signifikan meningkatkan kemampuan siswa dalam merencanakan, memantau, dan meregulasi proses belajar mereka. Penelitian ini menyimpulkan bahwa penggabungan konteks pembelajaran yang bermakna secara budaya dengan persiapan pra-kelas yang terstruktur serta pemecahan masalah STEM yang aktif di dalam kelas memberikan pendekatan yang kuat untuk memperkuat SRL.

***Kata kunci**: Budaya lokal; flipped classroom; kemandirian belajar; STEM.*

AKSIOMA: Jurnal Program Studi Pendidikan Matematika ISSN 2089-8703 (Print)
Volume 15, No. 2, 2026, 1243-1255 ISSN 2442-5419 (Online)

DOI: https://doi.org/10.24127/ajpm.v15i2.14992

INTRODUCTION

Twenty-first-century education requires learners to thrive in increasingly complex and technology-driven environments, necessitating the development of competencies such as scientific literacy, critical thinking, creativity, collaboration, and the capacity to regulate and direct their own learning (Trilling & Fadel, 2022). In response to these evolving educational demands, science and mathematics educators have increasingly turned to the Science, Technology, Engineering, and Mathematics (STEM) framework as a comprehensive pedagogical approach. STEM education seeks to integrate disciplinary knowledge and skills in ways that mirror authentic problem contexts, thereby fostering more meaningful and transferable conceptual understanding (English, 2016). A substantial body of research demonstrates that STEM-based instruction can promote learners' problem-solving abilities, creativity, and self-regulated learning, positioning it as a central strategy for advancing twenty-first-century skills (Li et al., 2020; Mouboua et al., 2024).

Parallel to the rise of STEM education, the Flipped Classroom model has emerged as a transformative instructional approach that reconceptualizes the traditional sequence of instruction. By relocating direct instruction to preclass learning materials and dedicating classroom time to collaborative, inquiry-driven, and higher-order cognitive activities, the Flipped Classroom encourages active learning, sustained student engagement, and deeper conceptual processing (Salami, 2024). When employed alongside STEM-based pedagogies, this model has been shown to enhance conceptual mastery, increase student autonomy, and stimulate deeper engagement with interdisciplinary tasks (Awidi & Paynter, 2019; Sun et al., 2017). Conse-quently, the combination of STEM and the Flipped Classroom model has gained recognition as a promising pedagogical innovation capable of supporting students' cognitive and metacognitive development.

Despite these documented advantages, an emerging body of literature highlights a critical limitation within technology-enhanced learning environments and STEM-based instruction: the insufficient consideration of cultural relevance (Tan et al., 2022). Culturally responsive pedagogy emphasizes the need to connect instructional content with students' cultural identities, community values, and lived experiences. Such connections are known to enhance learners' motivation, strengthen academic identity, and increase participation by affirming the relevance of schooling to students' personal and social worlds (Picpican et al., 2025; Ladson-Billings, 2021). Within the context of STEM learning, integrating local cultural values can enrich the learning experience by situating scientific and mathematical concepts within familiar cultural frameworks and everyday practices. This alignment has been shown to deepen conceptual understanding and promote greater learner involvement (Susilawati et al., 2024). However, current analyses reveal that only limited research has systematically examined how cultural values can be intentionally embedded within a STEM learning design implemented through a Flipped Classroom framework.

A review of recent scholarship highlights several pressing gaps. First, studies that explore the integration of cultural elements in education remain concentrated in fields such as literacy and social sciences, resulting in a scarcity of research investigating

DOI: https://doi.org/10.24127/ajpm.v15i2.14992

cultural integration within technology-supported STEM instruction (Azano & Stewart, 2015). Second, although the Flipped Classroom has been widely studied, only a small number of investigations address how culturally grounded learning materials can be effectively incorporated into both the pre-class and in-class phases to support students' self-regulated learning processes. Third, while a growing number of studies have examined outcomes such as learning motivation and conceptual mastery, empirical evidence remains limited regarding the direct effect of culturally situated STEM-Flipped Classroom designs on students' self-regulated learning—an essential determinant of long-term academic success and learner autonomy (Li et al., 2020; Sun et al., 2017).

Grounded in these identified gaps, the present research highlights two central problems: (1) the need for an instructional model that meaningfully integrates local cultural values within a STEM learning design situated in a Flipped Classroom environment, and (2) the lack of empirical evidence regarding how such integration may influence students' self-regulated learning. In response, this study proposes that embedding local cultural values into STEM-Flipped Classroom instruction will significantly enhance students' self-regulated learning compared to conventional approaches.

To address these challenges, the research develops a culturally enriched STEM-Flipped Classroom model. In this model, pre-class materials are contextualized using culturally relevant practices, artifacts, and narratives, while in-class activities involve culturally grounded projects, hands-on investigations, and collaborative problem-based tasks. This design aims not only to improve conceptual understanding but also to create meaningful learning experiences that affirm students' cultural identities, strengthen engagement, and support the development of internal learning regulation mechanisms.

Unlike previous studies that generally combine STEM instruction with flipped learning or incorporate cultural contexts as supplementary examples, this study proposes a Culture-Integrated STEM–Flipped Classroom (CI-STEM-FC) Framework, in which local cultural values function as the central pedagogical element throughout all phases of learning. Rather than positioning culture as contextual enrichment alone, the proposed framework embeds cultural knowledge into pre-class learning resources, classroom STEM investigations, collaborative engineering design activities, and reflective learning processes.

The framework integrates four complementary components: (1) culturally contextualized pre-class learning, where students independently explore mathematical concepts through videos and digital materials grounded in authentic local cultural practices; (2) inquiry-based STEM exploration in which students investigate mathematical phenomena embedded in cultural artefacts; (3) collaborative engineering design activities requiring learners to design, evaluate, and improve culturally inspired products using STEM principles; and (4) reflective self-regulated learning cycles that encourage planning, monitoring, strategy regulation, and self-evaluation throughout the learning process.

Consequently, the proposed framework extends existing flipped STEM models by introducing culture as the pedagogical core that simultaneously enhances conceptual under-

AKSIOMA: Jurnal Program Studi Pendidikan Matematika ISSN 2089-8703 (Print)
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standing, learner engagement, and self-regulated learning**.** This integration constitutes the principal theoretical contribution of the present study.

Aligned with this conceptual and empirical foundation, the study aims to: (1) examine the effectiveness of integrating local cultural values into STEM learning delivered through a Flipped Classroom model in enhancing students' self-regulated learning; (2) describe the implementation process of the developed instructional design; and (3) identify which dimensions of self-regulated learning exhibit the greatest improvement. The findings are expected to make theoretical contributions to the field of culturally responsive STEM education and offer practical guidance to educators seeking to design innovative, culturally grounded instructional practices suited to the needs of learners in the digital age.

METHODS

This study applied a quasi-experimental design using a *pretest–posttest control group design* (Weyant, 2022), involving an experimental group that received culturally integrated STEM–Flipped Classroom instruction and a control group that received conventional instruction. The population consisted of six Grade VIII classes (N = 192 students). Because the school administration did not permit individual random assignment, intact classrooms were used as sampling units. Each class name was coded numerically, and two classes were randomly selected using a computer-generated random number procedure. The first selected class served as the experimental group (n = 32), whereas the second served as the control group (n = 32). This procedure minimized selection bias while maintaining the natural classroom setting commonly recommended for quasi-experimental educational research. Quasi-experimental sampling procedures align with recommendations for school-based intervention studies. In alignment with recommendations for school-based intervention studies, this study employed a non-probability cluster sampling approach, selecting whole, intact classrooms as the sampling units to preserve the natural educational setting (Weyant, 2022). The study was conducted over six weeks in a junior high school mathematics course on circles.

The treatment instruments developed for this intervention consisted of instructional and task-based materials. First, the pre-class flipped learning media comprised eight video episodes (7–10 minutes, 720p MP4) uploaded to YouTube. These videos featured digital animations that isolated specific Geometric transformation formulas found within the architectural dimensions of specific Batik conceptual structures. Second, the STEM-project worksheets (LKPD) were structured around an engineering design process (EDP). The worksheets challenged students to solve a hands-on problem: [e.g., designing a stable miniature prototype of a traditional roof using popsicle sticks]. This task required students to calculate mathematical angles, test structural load-bearing capacities (engineering), and utilize digital measuring tools (technology).

Self-regulated learning was assessed using a 30-item Likert-scale questionnaire, evaluated for reliability and accepted at α ≥ 0.70 as recommended by (Blahuš et al., 2026). LMS analytics including *view duration* and *completion percentage*—were used to capture pre-class engagement, following learning analytics procedures described by (Qazdar et al., 2022).

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The self-regulated learning questionnaire, employed as the research instrument, was initially evaluated for content validity, criterion validity, and reliability. The results of expert validation with three experts demonstrated that all learning gadgets and research instruments were valid because the Aiken's V index value was higher than 0.4, which is the lowest level of validity. Cohen's kappa coefficient was used to measure how much agreement there was among experts. The result was $\kappa = 0.612$, which means that there was moderate agreement among the raters. The self-regulated learning questionnaire had a content validity index of 0.816. Both figures are at least 0.8, which shows that they are pretty accurate. As a result, it can be assumed that the research tool that was made meets the validity standards and is suitable for use in the next testing step. The Rank-Spearman correlation was utilized to see if the instrument was valid for what it was meant to do. This connection examines the degree to which each item aligns with the overall score of its concept. The item is real if the correlation coefficient is higher than the important value at the 0.05 significance level.

This indicates that the inquiry effectively assesses the intended latent variable. The same procedure was used to make sure that the items on the self-regulated learning questionnaire were correct. Twenty of the 35 statements were judged to be true, and 15 were found to be false. After confirming the validity of the items, a reliability study was conducted to assess the internal consistency of the instrument before proceeding to further statistical analysis. We utilized Cronbach's Alpha to see how reliable the self-regulated learning questionnaire was. The result was 0.791, which is greater than the recommended limit of 0.70. This means that the questionnaire is reliable. The learning tool and research instrument employed in this work were demonstrated to be valid and reliable, indicating their suitability as measurement tools in research. The self-regulated learning measure was evaluated for reliability with 64 students.

The N-gain formula (Ocholla et al., 2025) is used to figure out how much better things improved after utilizing educational games. Table 1 illustrates the results of the N-gain computation based on several different standards. After figuring out the gain, the next step is to find out how big the effect is. The effect size test tells you how effectively a treatment works and how it works (Borenstein, 2023). This study's effect size test sought to determine the magnitude of the STEM *Flipped Classroom* influence on students' creative thinking skills and self-regulated learning. Effect Size Criteria (Cohen, 2013). Improvement was evaluated using absolute gain scores (posttest–pretest difference), followed by effect size estimation using Cohen's d.

Researchers identified local cultural values relevant to circle-based mathematics content and embedded them into the pre-class videos and STEM project tasks. The self-regulated learning instrument was piloted on a comparable student population to ensure reliability (Blahuš et al., 2026; Ohta et al., 2023).

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Table 1. Learning Syntax of Culture-Integrated STEM–Flipped Classroom

Phase	Learning Activities	STEM Component	SRL Component
Orientation	Teacher introduces cultural phenomenon	Science	Goal setting
Pre-Class	Students watch culture-based videos	Technology	Planning
Exploration	Investigate cultural artifact	Science	Monitoring
Engineering Design	Design prototype	Engineering	Strategy regulation
Mathematical Modelling	Solve mathematical problems	Mathematics	Self-monitoring
Reflection	Present, evaluate and revise	Integrated STEM	Self-evaluation

RESULTS AND DISCUSSION

Before the main statistical tests, checks were done to make sure that parametric analyses were appropriate. The Shapiro–Wilk test showed that the scores for both the experimental and control groups before and after the test were normally distributed ($p > .05$). Levene's test showed that the variances were the same across groups ($F(1,62) = 1.27$, $p = .26$). These results satisfied the prerequisites for the independent samples t-test and gain-score analyses, as advised by Field et al., (2025). Descriptive statistics also showed that the first self-regulated learning scores were similar for both groups: the experimental group had an average of 105.14 with a standard deviation of 9.87, while the control group had an average of 104.28 with a standard deviation of 10.42. The difference was not statistically significant ($t(62) = 0.48$, $p = 0.63$), which means that the starting conditions were the same.

After the six-week intervention, significant enhancements were noted in the experimental group that participated in the culturally integrated STEM–Flipped Classroom training. The experimental group had a higher mean score on the posttest ($M = 118.42$, $SD = 9.31$) than the control group ($M = 108.19$, $SD = 10.14$). The difference between the two groups was statistically significant ($t(62) = 5.12$, $p < 0.001$), which shows that the instructional intervention worked.

These results are in line with other studies by Awidi & Paynter, (2019); Sun et al., (2017), which found that Flipped Classroom models increase student participation, encourage independence, and give students more time to think about what they are learning. The integration of cultural elements within STEM instruction likely strengthened these effects by increasing relevance, fostering a sense of connection, and supporting conceptual understanding through culturally meaningful experiences.

Overall, the results demonstrate that the culturally integrated STEM–Flipped Classroom approach is effective not only in developing self-regulated learning skills but also in offering a more engaging and contextually meaningful learning experience. These findings underscore the importance of pedagogical innovations that blend technological tools, constructivist principles, and cultural relevance in modern educational practice.

Gain score analysis further revealed that the experimental group achieved a substantially greater improvement ($M = 13.28$) than the

ISSN 2089-8703 (Print)
ISSN 2442-5419 (Online)

DOI: https://doi.org/10.24127/ajpm.v15i2.14992

control group (M = 5.44). The effect size, computed using Cohen's d (Yuan & Zhang, 2025), yielded d = 0.88, which falls into the large effect category. This strong effect demonstrates that integrating cultural values within a STEM–Flipped model substantially improves students' capacity to regulate their learning processes.

This strong effect can be explained by the way the intervention aligns with the cyclical nature of SRL. The flipped component strengthens the forethought phase by requiring students to plan, set goals, and prepare before class (e.g., organizing time and identifying what they do not understand). During in-class STEM activities, students are pushed into the performance/monitoring phase, where they must select strategies, test ideas, collaborate, and adjust approaches when obstacles arise behaviors that directly reflect self-monitoring and strategy control. Finally, post-class consolidation and reflection activities support the self-reflection phase, encouraging students to evaluate outcomes and refine strategies for future tasks (Panadero, 2020; Peeters & Mynard, 2023). The STEM problem-solving environ-ment is particularly well-suited to building SRL because it normalizes iteration (try–test–revise), which trains students to persist, track progress, and regulate effort.

Importantly, the "culture-integrated" element likely amplified these SRL gains by increasing relevance and meaning. When tasks reflect students' cultural experiences or values, learners often demonstrate stronger engagement and ownership, which supports motivational regulation and persistence two critical drivers of SRL growth. Cultural integration can also reduce perceived distance between school knowledge and everyday life, making students more willing to invest effort, seek resources, and treat difficulties as challenges rather than threats. Therefore, the large effect observed here plausibly reflects a synergy: the flipped structure builds routines and accountability for independent preparation, STEM tasks require active regulation in complex problem spaces, and cultural relevance strengthens motivation and sustained engagement together producing substantial SRL improvement.

From an instructional standpoint, these results imply that teachers who aim to develop SRL should not rely solely on strategy training in isolation, but should design a learning ecosystem that (a) requires structured pre-class preparation, (b) uses STEM tasks that demand monitoring and iterative decision-making, and (c) anchors problems in culturally meaningful contexts to sustain motivation. Nevertheless, future work could strengthen the evidence by triangulating SRL gains with behavioral indicators (e.g., LMS access logs, completion rates, time-on-task) and by examining whether the effect remains large across different student ability levels, durations of implementation, and cultural contexts.

LMS analytics provided further insight into students' engagement patterns. Students in the experimental group who watched at least 75% of each pre-class video showed higher posttest scores (M = 120.88) than those who watched less (M = 113.47). Correlation analysis indicated a moderate relationship between LMS engagement and self-regulated learning ($r = .41$, $p < .01$), supporting Susilawati et al., (2024) who argue that digital engagement is a reliable predictor of learning performance. These findings underscore the essential role of the pre-class

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ISSN 2442-5419 (Online)

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component in the Flipped Classroom model and highlight how culturally relevant content may increase students' willingness to engage with instructional materials.

To get a more comprehensive depiction of students' self-regulated learning profiles, the distribution of each self-regulated learning indicator was further illustrated using a clustered bar chart. Figure 1 presents a comparison of the percentage scores across eight self-regulated learning (SRL) indicators between the control and experimental groups. The indicators include: learning initiative and motivation; diagnosing learning needs; formulating learning goals; selecting and implementing learning strategies; utilizing and seeking relevant resources; evaluating the learning process and outcomes; viewing difficulties as challenges; and managing, controlling, and monitoring learning activities. This comparison is intended to describe how SRL achievement varies by indicator across the two groups.

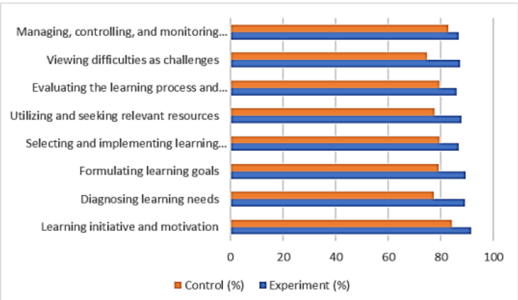

Figure 1. Clustered Bar SRL

Based on Figure 1, the experimental group shows higher SRL percentages than the control group across all indicators. The control group generally falls within approximately 75–85%, whereas the experimental group is around 85–95%. The most noticeable gaps appear in "viewing difficulties as challenges" and "formulating learning goals," suggesting that the experimental intervention more effectively fostered students' resilience and their ability to set clear learning targets.

In addition, higher scores in "diagnosing learning needs" and "utilizing and seeking relevant resources" indicate that students in the experimental group were better able to identify what they needed to learn and were more proactive in seeking relevant learning resources. Overall, the pattern in the figure suggests that the intervention contributed positively to strengthening students' self-regulation, particularly in planning, strategy implementation, and the monitoring and evaluation of learning.

The pattern in Figure 1—showing consistently higher percentages for the experimental group across all eight SRL indicators—suggests that the Culture-Integrated STEM Flipped Classroom helped students engage more fully in the core phases of self-regulation: planning/goal-setting, strategic action and monitoring, and reflection/ evaluation. This interpretation aligns with widely used SRL models that conceptualize self-regulation as a cyclical process involving forethought, performance/monitoring, and self-reflection (Panadero, 2020; Peeters & Mynard, 2023), and with integrative reviews emphasizing that SRL includes cognitive, motivational, behavioral, and contextual regulation that unfolds across phases (Panadero, 2020).

From a learning-design perspective, the flipped structure likely contributed to these gains because it increases students' autonomy and responsibility during the pre-class phase (e.g., managing time, identifying what is not understood, preparing questions), while in-class time can be devoted to struc-

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tured active learning (discussion, problem solving, and feedback), which naturally elicits strategy use and monitoring. Meta-analytic evidence indicates that flipped classrooms yield better learning outcomes than non-flipped instruction, and that effectiveness is strengthened when designs include quizzes and do not reduce face-to-face learning time features that also function as accountability and formative feedback mechanisms supporting SRL (Strelan et al., 2020; van Alten et al., 2020). In addition, research specifically examining SRL supports in flipped environments shows that embedding prompts and explicit SRL guidance into learning materials (e.g., videos) can enhance learning outcomes (van Alten et al., 2020), and a recent systematic review argues that effective SRL support in flipped classrooms typically requires a *combination* of guidance plus opportunities to practice SRL strategies rather than relying on a single method (LIU et al., 2024).

The "culture-integrated" component provides an additional explanation for why the experimental group outperformed the control group across indicators—particularly those related to goal formulation and viewing difficulties as challenges. Culturally meaningful contexts can increase relevance, agency, and engagement, which are closely tied to motivational regulation and persistence (a key SRL resource when tasks become difficult). In line with this, the Culturally Responsive Self-Regulated Learning (CR-SRL) Framework emphasizes that SRL is shaped by the interaction between learners and sociocultural context, and that integrating culturally responsive pedagogical practices with SRL-promoting practices can support more meaningful engagement in complex tasks (Anyichie et al., 2023; Anyichie & Butler, 2017). Thus, when STEM tasks are situated in students' cultural experiences (not merely as examples, but as the basis for inquiry/design problems), students may be more willing to persist through challenge, refine strategies, and evaluate outcomes behaviors reflected in the higher SRL indicator percentages for the experimental group.

The significant improvement in self-regulated learning within the experimental group reinforces the idea that learners develop stronger autonomy when instructional models position them as active agents in their learning (Ohta et al., 2023).

The Flipped Classroom's structure encourages responsibility and time management as students must engage with content independently. This mirrors findings by (Awidi & Paynter, 2019; Salami, 2024) who reported similar outcomes in diverse educational contexts.

The novelty of this study lies in its cultural integration. Embedding local cultural values in STEM tasks not only contextualized learning but also fostered emotional and cognitive engagement consistent with culturally responsive pedagogy (Picpican et al., 2025; Ladson-Billings, 2021). This deeper engagement likely contributed to the increased self-monitoring, strategic regulation, and self-reflection observed in the experimental group. Students may have experienced a sense of identity affirmation and relevance, leading to enhanced learning ownership a pattern also noted by Susilawati et al., (2024) in culture-integrated STEM models.

Local Cultural Context

The local cultural context employed in this study was derived from traditional Batik geometric motifs

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DOI: https://doi.org/10.24127/ajpm.v15i2.14992

and vernacular architecture widely recognized in the students' community. Batik motifs were selected because they contain rich mathematical structures, including circles, symmetry, transformations, tessellations, proportional reasoning, and geometric patterns. Meanwhile, traditional roof constructions were utilized as authentic engineering contexts for STEM-based design activities. These cultural artefacts were selected based on three criteria: (1) familiarity to students, (2) strong mathematical representation, and (3) relevance to engineering design activities. Consequently, culture functioned not merely as contextual decoration but as an authentic source of mathematical inquiry throughout the learning process.

Limitations

This study has several limitations. First, the intervention involved students from only one junior high school, limiting the generalizability of the findings. Second, the implementation focused exclusively on circle topics, and therefore the effectiveness of the proposed model in other mathematical domains remains to be investigated. Third, although the findings demonstrate substantial improvements in self-regulated learning, future studies involving multiple schools, broader cultural contexts, and longitudinal implementation are necessary to strengthen external validity.

CONCLUSIONS

This study demonstrates that integrating local cultural values into STEM learning through a Flipped Classroom model significantly enhances students' self-regulated learning. Students in the experimental group showed greater improvement in all four indicators planning, monitoring, strategy regulation, and self-evaluation compared to those taught using conventional instruction. The large effect size further indicates that this culturally enriched instructional approach not only improves learning outcomes but also strengthens students' autonomy and engagement. Additionally, LMS analytics revealed that higher pre-class engagement is positively associated with increased self-regulated learning, confirming the critical role of structured pre-class activities in the Flipped Classroom model.

Based on the findings of this study, it is recommended that teachers integrate local cultural contexts into STEM learning activities to enhance students' motivation, engagement, and sense of relevance, while simultaneously utilizing the Flipped Classroom structure to promote stronger habits of autonomous learning. Schools should provide adequate technological support, particularly reliable Learning Management Systems, to ensure that pre-class engagement can be monitored effectively and used to inform instructional decisions during face to face sessions. Future research is encouraged to involve larger and more diverse samples, employ mixed-method approaches to capture deeper insights into learners' experiences, and examine long-term impacts of culturally enriched STEM–Flipped Classroom models on students' self-regulated learning and overall academic development. Such efforts will contribute to refining pedagogical frameworks and strengthening the evidence base for culturally responsive STEM education.

The proposed instructional framework provides mathematics teachers with a practical strategy for integrating culturally meaningful contexts into

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STEM-oriented flipped learning. Rather than teaching mathematical concepts in isolation, teachers may employ authentic local cultural artefacts as inquiry objects that stimulate higher-order thinking and autonomous learning. Furthermore, curriculum developers may adopt the proposed framework as a reference for designing culturally responsive STEM curricula aligned with twenty-first-century competencies and national curriculum objectives.

ACKNOWLEDGEMENT

The Hibah Risetmu IX grant from the Majelis Pendidikan Tinggi, Penelitian, dan Pengembangan (Majelisdiktilitbang) Pimpinan Pusat Muhammadiyah helped pay for this research. The authors would like to thank everyone who helped them with money and support from their institutions, which made this work feasible.

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