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METACOGNITIVE SKILLS AND STUDENT ENGAGEMENT IN STEAM HIGHER EDUCATION: A GENDER-BASED ANALYSIS

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ABSTRACT

Metacognitive skills allow learners to plan, regulate, and reflect on their own learning, essential for successful learning in STEAM disciplines where creativity and problem-solving are key to success. Student engagement—which can be viewed through behavioral, emotional, and cognitive responses—also plays a key role in academic performance. The current study explores the association between metacognitive ability and student engagement between genders and explores the role of metacognitive skill in supporting different engagement dimensions in STEAM undergraduates. A descriptive-correlational study was performed on a sample of 400 students who were enrolled in the STEAM program in Haryana and then used stratified random sampling technique. Data were collected according to standardized scales (MCA-I and USEI) and analysed by Mann–Whitney U test, Pearson correlation, and simple linear regression in JAMOVI. Girls scored higher in metacognitive performance and engagement than boys in both of the variables (non-parametric tests, $p < .001$). A positive relationship with engagement was found for metacognitive skills ($r = .226$, $p < .001$). Regression results confirmed that metacognitive skills were meaningful predictors of behavioral ($R^2 = .0166$, $p = .010$), emotional ($R^2 = .0367$, $p < .001$), and cognitive engagement ($R^2 = .0561$, $p < .001$). The findings indicated that increased metacognitive awareness was associated with improved performance on STEAM learning tasks. Thus, teaching strategies that emphasize metacognitive development may improve students' participatory ability and learning quality. It remains suggested that, in the future, increased modeling and further samples of more diverse populations should be integrated to enhance the generalization.

Keywords: Metacognition, Engagement, Gender Differences, STEAM Learning, Predictive Analysis

1. INTRODUCTION

Science, technology, engineering and mathematics (STEM) are at the very base of contemporary education. But when it has been interpreted in a broader sense, expanding to the arts including creativity, design thinking, and humanities aspects, the framework becomes STEAM, emphasizing the interaction between creative domain and technical domain Clark et al. (2024). STEAM education encourages innovation, development of integrated thinking and flexible problem solving for students to tackle complex, interdisciplinary challenges. In view of this logic, metacognition (sometimes referred to as "thinking about thinking"; Flavell (1979) has emerged as increasingly salient to the understanding of effective learning. Metacognitive skills enable learners to plan, keep track, and assess their response in

order to develop the self-regulation and critical thinking needed to participate in task-based learning. At the same time, student engagement—characterized by behavioral, emotional, and cognitive dimensions Fredricks et al. (2004)—is a well-established predictor of persistence and achievement in higher education. STEAM education is thus a rich field for embedding metacognitive approaches while providing opportunities to promote deeper engagement, creativity, and problem-solving. Metacognitive skills — which encompass watching, regulation, and evaluation of cognitive activity — are widely accepted as central to deep learning and problem-solving Efklides (2018), OECD (2021). In STEAM disciplines—where creativity and adaptability matter—those skills serve as the connective tissue between surface-level learning and higher-order cognitive engagement. Structured metacognitive frameworks were recently shown to be beneficial to outcomes This structured guidance greatly enhanced learners' ability to identify gaps in reasoning as well as persistence on complex tasks. Similarly, Clark et al. (2024) reported weekly reflective practices in flipped STEM classrooms led students to self-regulate better and to show significant increases in their exam performance. These findings are consistent with previous studies demonstrating that explicit metacognitive instruction enhances conceptual understanding and facilitates independent learning Rickey and Stacy (2000). Investigations across fields have also reinforced the role metacognition plays in STEAM education. Alzahrani (2022) discovered positive association of metacognitive awareness with participation in STREAM education, which also had advantages over thinking critically and independent learning. Similarly, Henriksen et al. (2021) showed that integrating metacognitive strategies with creative thinking practices enhanced learner flexibility and their reflective capacities. Other studies emphasize the transformative role of technology. González-Gómez and Pérez-Fernández (2021) note that STEM-based online education increased metacognitive awareness by 30% and creative thinking also by 45% — in favor of the role of digital platforms, which are supportive of cognitive and creative growth. Likewise, Markandan et al. (2022) formulated the ME-CoT module that was found to have good results in promoting the reflective skills and active engagement amongst biology students with computational thinking. Studies also suggest the potential of metacognitive approaches to be inclusive. Nguyen Thi Hoang et al. (2022) described how reflective processes in STEAM tasks enhanced self-awareness in students with learning disabilities, forming a multi-dimensional basis for equitable education. Student Engagement in STEAM Participation has been understood as a multi-dimensional value that includes behaviors, emotions, and thought Fredricks et al. (2016). Engagement is positively associated with persistence, gratification, and academic performance in the presence of engagement Christenson et al. (2012). Engagement is especially important in STEAM fields because learning involves collaboration, problem-solving, and collaborative problem-solving. For instance, evidence suggests that metacognitive strategies increase engagement. Specifically, Akamatsu et al. (2019) found that planning and monitoring behaviors improve self-efficacy, which increases persistence of learning. For example, Ünsal-Görkemoğlu and Karacan (2024) determined that metacognitive awareness increased Turkish EFL learners' participation in writing tasks, which in turn improved academic achievement. In this study, Taghani and Razavi (2022) showed that structured metacognitive study skills training produced a significant effect in self-efficacy, academic engagement, and performance of the female high school students. Engagement is also supported by technology-enhanced approaches. Ahmadaliev et al. (2022) found that educational robotics (ER) training resulted in increased reflective thinking and enjoyment and increased engagement levels in middle school students. Nasir et al. (2024) also found that embedding metacognitive strategies in STEAM project-based learning (STEAMPjBL) facilitates collaboration, creativity, and self-regulated learning, thus enriching the students' experience. Literature review highlights the interdependent nature of metacognitive skills and the engagement of students in the process of STEAM learning. Metacognitive approach is not only associated with better academic results but also contributes to a better student-motivation, persistence, and reflective ability. Research from both traditional and technology-mediated learning environments shows that the inclusion of high level metacognitive support promotes enhanced creativity, better conceptual understanding and inclusivity. Notwithstanding these advances, research directly linking metacognition in STEAM to engagement is still comparatively sparse. Future studies should also investigate how particular instructional characteristics (e.g., project-based, computational learning) mediate this relationship across different populations. Introducing metacognitive instruction as part of a focused pedagogical approach is a valuable approach to prepare learners with the adaptability, creativity, and resilience essential to 21st-century STEAM learning.

2. OBJECTIVES OF THE STUDY

1) To Examine the differences in metacognitive skills between boys and girls among STEAM
2) To Examine the differences in student engagement between boys and girls among STEAM

3) To analyze the relationship between metacognitive skills and student engagement among STEAM

3. HYPOTHESES

H01: There is no significant difference in the mean scores of metacognitive skills between boys and girls of STEAM undergraduates.

H02: There is no significant difference in the mean scores of student engagement between boys and girls of STEAM undergraduates.

H03: There is no significant relationship between metacognitive skills and student engagement among STEAM undergraduates.

H04: Metacognitive skills significantly predict behavioral engagement among STEAM undergraduates.

H05: Metacognitive skills significantly predict emotional engagement among STEAM undergraduates.

H06: Metacognitive skills significantly predict cognitive engagement among STEAM undergraduates.

4. METHODOLOGY

4.1. RESEARCH DESIGN

Descriptive and correlational, quantitative.

4.2. SAMPLE

400 undergraduate STEAM students in a variety of colleges throughout Haryana are selected using stratified random sampling.

4.3. TOOLS

Metacognitive Activities Inventory (MCA-I), developed by Cooper et al. (2008). The MCA consists of 27 items that serve as an instrument for students' metacognitive behaviors in academic learning situations. Items on a 5-point Likert scale range from 1 = Strongly Disagree to 5 = Strongly Agree. It has shown good reliability and construct validity, with Cronbach's alpha coefficients > 0.70 on subscales Cooper et al. (2008). The University Student Engagement Inventory (USEI) was designed by João Marôco, et al in 2016 to create a 15-item self-report questionnaire for students at university. It measures academic engagement rate in university students by the students. This scale: 15-item questionnaire for assessing engagement in higher education across:

1) Cognitive Engagement – the degree to which learners commit to learning and self-regulation.
2) Emotional Engagement – students' emotional involvement and sense of belonging.
3) Behavioral Engagement – the extent to which students participate in the academic learning activities students are doing.

The responses are stored according to a 5–point Likert-type scale from 1 (Strongly Disagree) to 5 (Strongly Agree). The scale has shown good psychometric properties and is validated in numerous cultural contexts, with Cronbach's alpha coefficients above the recommended level of 0.70 for all three subscales (Marôco et al., 2016).

5. RESULTS

A total of 400 STEAM undergraduates participated in the survey, responding to a 27-item Metacognitive Skills Scale on a 5-point Likert scale (1 = Strongly Disagree to 5 = Strongly Agree). The response were scored by averaging across all items, with interpretation thresholds set

For categorical distribution:

Moderate level: 215 students (53.75%)

High level: 176 students (44.00%)

Low level: 9 students (2.25%)

This distribution suggests that nearly half of the students exhibit high metacognitive skills, while just over half fall within the moderate range, and only a small proportion demonstrate low metacognitive competence. The relatively small low-level group indicates a generally strong metacognitive profile among STEAM undergraduates, though targeted interventions may be required to support those in the lower range.

Table1

Table 1 Gender Differences in Metacognitive Skills Scores among STEAM Undergraduates

Variable	Group	N	Mean	SD	Mean Difference	Cohen's *d*
Metacognitive Skills	Male	200	61.9	14.7	6.15	0.47
	Female	200	68.0	11.4		

Note. Mean difference was calculated as female − male scores. Cohen's d indicates a medium effect size.

Table 1 reported that metacognitive skills scores between males and females. Males (M = 61.9, SD = 14.7, n = 200) had significantly lower metacognitive skills scores than females (M = 68.0, SD = 11.4, n = 200). The mean difference was 6.15, indicating that females scored higher on average. The effect size, as measured by Cohen's d, was 0.47, suggesting a medium effect size.

Table 2

Table 2 Comparison of Metacognitive Skills by Gender (Mann–Whitney U Test)

Variable	Group	N	Mean Rank	U	*p*
Metacognitive Skills	Male	200	176.44	13589	< .001
	Female	200	224.56		

Note. Mann–Whitney U test was used to examine gender differences in metacognitive skills.

The difference between male and female students was statistically significant (p < .001)

Table 2 reports that A Mann-Whitney U test indicated a statistically significant difference in metacognitive skills scores between males and females, U = 13,589, p < .001. The mean rank for females (224.56) was higher than that for males (176.44), suggesting that metacognitive skills scores were stochastically superior for females compared to males.

Table 3

Table 3 Gender Differences in Student Engagement Scores among STEAM Undergraduates

Variable	Group	N	Mean	SD	Mean Difference	Cohen's *d*
Student Engagement	Male	200	42.8	9.96	−17.6	1.48
	Female	200	60.4	13.0		

Note. Mean difference was calculated as male − female scores. Cohen's d indicates a large effect size.

Table 3 presents the results gender differences in student engagement among STEAM undergraduates. The findings indicate that female undergraduates (M = 60.4, SD = 13.0) demonstrated significantly higher levels of student engagement than male undergraduates (M = 42.8, SD = 9.96). The magnitude of the difference was large (Cohen's d = 1.48), suggesting a substantial practical significance.

Table 4

Table 4 Mann–Whitney U Test Results for Gender Differences in Student Engagement among STEAM Undergraduates

Variable	Group	N	Mean Rank	*U*	*p*
Student Engagement	Male	200	176.44	5,785	< .001
	Female	200	224.56		

Note. Mann–Whitney U test was used to examine gender differences in student engagement.

Higher mean ranks indicate higher levels of student engagement.

Table 4 presents the results of the Mann–Whitney U test examining gender differences in student engagement among STEAM undergraduates. The analysis revealed a statistically significant difference between male and female students, U = 5,785, p < .001. Female undergraduates exhibited higher mean ranks in student engagement than their male counterparts, indicating that student engagement scores for the female group were stochastically superior to those of the male group. These findings suggest that female STEAM undergraduates are more actively engaged across academic, behavioral, and emotional dimensions of learning.

Table 5

Table 5 Correlation between Metacognitive Skills and Student Engagement among STEAM Undergraduates

Variables	*r*	*df*	*P*	95% CI LL	95% CI UL
Metacognitive Skills – Student Engagement	.226	398	< .001	.130	.317

Note. Pearson's correlation coefficient (r) was used. CI = confidence interval; LL = lower limit; UL = upper limit.

A Pearson correlation analysis revealed a statistically significant positive relationship between metacognitive skills and student engagement, r(398) = .226, p < .001. This indicates that higher levels of metacognitive skills are associated with higher levels of student engagement.

Table 6

Table 6 Simple Linear Regression Predicting Behavioral Engagement from Metacognitive Skills

Predictor	*B*	*SE*	*t*	*P*	95% CI	R^2	*F*(df)
Metacognitive Skills	0.0429	0.0165	2.59	.010	[0.010, 0.075]	.0166	6.72 (1, 398)
Intercept	14.6697	1.0975	13.37	< .001	[12.514, 16.825]	—	—

Note. R^2 represents the proportion of variance explained in behavioral engagement.

The regression model predicting behavioral engagement from metacognitive skills was statistically significant, F(1, 398) = 6.72, p = .010. Metacognitive skills significantly and positively predicted behavioral engagement (B = 0.0429, SE = 0.0165, t = 2.59, p = .010), explaining 1.66% of the variance (R^2 = .0166).

Table 7

Table 7 Simple Linear Regression Predicting Emotional Engagement from Metacognitive Skills

Predictor	*B*	*SE*	*t*	*P*	95% CI	R^2	*F*(df)
Metacognitive Skills	0.0465	0.0119	3.89	< .001	[0.023, 0.070]	.0367	15.12 (1, 398)
Intercept	7.6493	0.7935	9.64	< .001	[6.09, 9.21]	—	—

Note. R^2 indicates variance explained in emotional engagement.

The regression model significantly predicted emotional engagement, F(1, 398) = 15.12, p < .001. Metacognitive skills emerged as a significant positive predictor (B = 0.0465, SE = 0.0119, t = 3.89, p < .001), accounting for 3.67% of the variance in emotional engagement (R^2 = .0367).

Table 8

Table 8 Simple Linear Regression Predicting Emotional Engagement from Metacognitive Skills

Predictor	*B*	*SE*	*t*	*P*	95% CI	R^2	*F*(df)
Metacognitive Skills	0.153	0.0315	4.86	< .001	[0.091, 0.214]	.0561	23.62 (1, 398)
Intercept	13.501	2.0926	6.45	< .001	[9.39, 17.61]	—	—

Note. R^2 indicates variance explained in emotional engagement.

The regression model predicting cognitive engagement was statistically significant, F(1, 398) = 23.62, p < .001. Metacognitive skills significantly and positively predicted cognitive engagement (B = 0.153, SE = 0.0315, t = 4.86, p < .001), explaining 5.61% of the variance (R^2 = .0561).

6. DISCUSSION

The findings of this study support previous evidence that metacognitive skills are central to enhancing student engagement through planning, self-monitoring and learning process regulation. As seen in their most recent published research, students who are the active participants in the use of metacognitive strategies tend to demonstrate higher levels of engagement and persistence. Consistent with previous studies, females in the present study showed relatively high level of engagement, a process that has been attributed to a higher degree of metacognitive awareness and using of strategy in females Akin (2016), Abdelrahman (2020), Rickey and Stacy (2000). Similar trends are observed in other educational contexts, including that female learners report more investment and sustained attention in learning activities as well as persistent effort to engage Rismawati et al. (2021). In accordance with the gendered pattern found here, students with higher metacognitive awareness have higher intrinsic motivation, as also indicated that females possess significantly-stronger intrinsic motivation due to their higher academic achievement Döş and Eraslan (2024). Furthermore, a strong correlation has emerged from empirical data linking metacognitive ability to motivation and academic performance which implies that metacognitive regulation strategies aid in both instructional effectiveness and motivational strategies positively Deshmukh et al. (2025). Collectively, these findings add support to results in the present study, and emphasize the significance of explicitly incorporating cognitive and metacognitive strategy within STEAM instruction. Teaching strategies along these lines could be especially helpful for students with lower metacognitive proficiency, regardless of gender, so as to promote better self-monitoring, self-regulation, and continuation of academic effort. This research illustrates that addressing differences between students' metacognition is a first step to fostering culturally aware, equitable, and effective learning environments for all STEAM undergraduates.

7. CONCLUSION

This study identifies that STEAM undergraduates possess relatively moderate to high levels of metacognitive skills, of which a large proportion exhibit strong ability to regulate and reflect. Significant gender differences were observed in both in Mann–Whitney U tests, where girls had significantly superior metacognitive skills and student engagement compared to boys. The discrepancies did have substantial practical significance. The positive correlation results verify that students who possess higher levels of metacognitive skills tend to be more associated with behaviorally, emotionally, and cognitively engaged in their academic process. Regression models also confirmed metacognitive skills as a significant predictor for engagement throughout the three domains and their importance and central contribution to driving deep learning, persistence, and involvement. To this end, our findings clearly indicate the need for the inclusion of metacognitive training techniques embedded within STEAM classrooms to promote self-regulated learning processes and raise students´ level of motivation and engagement. Educators are empowered to offer targeted assistance to students—particularly boys and those with reduced metacognitive awareness—who are particularly at risk to be absent in learning, for equitable participation and achievement in academics. Further studies should leverage advanced modeling (e.g., SEM) to explore these relationships, causal directions for research design, and a sample in a broader geographical region for generalizability.

CONFLICT OF INTERESTS

None.

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