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A Framework-Based Investigation of Gender Differences in Meta-Affective Responses During Science Education in Vocational Secondary Schools

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ABSTRACT

This study develops a comparative analytical model to examine gender-based variations in meta-affective processes during science learning among vocational high school students. Meta-affect, defined as the awareness, regulation, and interpretation of one's own emotional states in learning contexts, plays a crucial role in shaping engagement, cognitive performance, and long-term academic resilience (DeBellis & Goldin, 2006). Drawing on affective learning theory, emotional intelligence frameworks, and engagement models, this research synthesizes prior empirical findings to construct a structured analytical model that explains how gender differences influence emotional regulation, learning engagement, and cognitive-affective interaction in science education.

The model integrates dimensions of emotional regulation, academic engagement, and socio-cognitive interaction, informed by prior studies on affective engagement and learning behavior (Daher et al., 2021; Fredricks et al., 2004). Special emphasis is placed on the role of emotion regulation training in shaping affective control and academic adaptation, as highlighted in experimental findings (Dehghani et al., 2018). The study further explores how cultural, psychological, and instructional factors interact with gender to produce differentiated meta-affective learning patterns.

Findings from the synthesized model suggest that female and male students exhibit distinct emotional regulation strategies and engagement trajectories in science learning environments. These differences are mediated by emotional intelligence, instructional support, and socio-cultural expectations. The proposed framework contributes to the theoretical advancement of meta-affective learning research and provides practical implications for vocational science education design, particularly in enhancing gender-responsive pedagogical strategies.

1. INTRODUCTION

1.1 Background of the Study

Science learning in vocational high schools requires not only cognitive mastery but also strong emotional and motivational regulation. Recent research highlights that affective and meta-affective processes significantly influence students' engagement, persistence, and problem-solving capabilities in science education (Azevedo, 2015; Ben-Eliyahu, 2019). Meta-affect refers to the learner's ability to monitor and regulate emotional responses during cognitive activities, particularly in challenging or problem-solving contexts (DeBellis & Goldin, 2006).

In vocational education settings, students often face applied science tasks that demand both technical reasoning and emotional resilience. Studies have shown that emotional regulation training can significantly improve academic burnout, affective control, and social adaptation among learners (Dehghani et al., 2018). Such findings emphasize that emotional processes are not secondary but central to academic achievement.

Gender differences further complicate this dynamic. Research indicates that male and female students may differ in emotional expression, regulation strategies, and engagement patterns in learning environments (Conley et al., 2020). These differences may influence how students interpret scientific content, respond to instructional challenges, and regulate frustration or anxiety during learning.

1.2 Problem Statement

Despite increasing recognition of affective factors in education, limited empirical and theoretical frameworks exist that specifically explain gender-based variations in meta-affective processes in vocational science learning. Existing studies tend to focus on either emotional intelligence or academic engagement separately, without integrating them into a unified meta-affective model. Furthermore, while interventions such as emotion regulation training have demonstrated effectiveness in improving academic outcomes (Dehghani et al., 2018), their implications for gender-specific learning behavior in science education remain underexplored.

1.3 Research Objectives

This study aims to:

1. Develop a comparative analytical model of gender-based meta-affective variation in science learning.

2. Identify the role of emotional regulation and engagement in shaping learning outcomes.

3. Synthesize existing literature to construct an integrated theoretical framework.

4. Provide implications for vocational science education pedagogy.

1.4 Scope and Significance

The scope of this research is limited to vocational high school students engaged in science learning contexts. The significance lies in its contribution to meta-affective theory, particularly in integrating gender as a moderating variable in affective learning processes. The study also supports educators in designing emotionally adaptive instructional strategies that improve engagement and reduce academic burnout.

2. LITERATURE REVIEW

2.1 Meta-Affect and Learning Processes

Meta-affect is conceptualized as the reflective awareness of emotional experiences during cognitive activity (DeBellis & Goldin, 2006). It extends beyond emotional intelligence by incorporating self-regulation during problem-solving tasks. In science education, meta-affective processes influence persistence when students encounter conceptual difficulty. Azevedo (2015) emphasizes that engagement in science learning is shaped by intertwined cognitive and emotional mechanisms, where affective regulation determines the depth of conceptual understanding.

Ben-Eliyahu (2019) further argues that academic emotional learning is a core component of self-regulated learning systems. Without effective emotional monitoring, learners are more likely to experience disengagement and reduced cognitive performance.

2.2 Emotional Regulation and Academic Outcomes

Emotional regulation plays a foundational role in academic success. Dehghani et al. (2018) demonstrated that structured emotion regulation training significantly reduces academic burnout while improving affective control and social acceptance among students with learning difficulties. This study is particularly relevant as it highlights how targeted interventions can enhance emotional stability and academic

adaptation. In vocational education contexts, such regulation becomes essential due to the applied and often high-pressure nature of science learning tasks.

The findings of Dehghani et al. (2018) are repeatedly supported across educational psychology literature, emphasizing that students with stronger emotional control demonstrate higher engagement and resilience.

2.3 Gender Differences in Affective Learning

Gender differences in emotional processing and learning behavior have been widely documented. Conley et al. (2020) show that psychological functioning and cognitive-affective strategies vary significantly between male and female students during college years. These differences extend into how students manage academic stress and engage with learning content.

Chong et al. (2018) also highlight that cognitive and affective engagement interact differently across learner groups, influenced by perceived self-efficacy and teacher support. Such findings suggest that gender may moderate the relationship between emotional engagement and academic performance.

2.4 Engagement in Science Learning

Student engagement is a multidimensional construct involving behavioral, cognitive, and emotional components (Fredricks et al., 2004). In science education, engagement is crucial for sustaining interest in abstract and complex concepts. Azevedo (2015) argues that engagement is not static but dynamically influenced by classroom interaction and emotional regulation.

Daher et al. (2021) extend this understanding by showing that affective engagement in online learning environments significantly predicts higher education student performance. This highlights the importance of emotional factors in both traditional and digital science education settings.

2.5 Emotion Regulation Training and Behavioral Adaptation

The role of emotion regulation training is central to improving learning outcomes. Dehghani et al. (2018) provide strong empirical evidence that structured emotional interventions enhance students' ability to manage academic stress and improve affective control. This improvement is critical in science learning contexts where students often encounter problem-solving stress and conceptual uncertainty.

Repeated findings from Dehghani et al. (2018) confirm that emotional training not only reduces negative academic outcomes but also strengthens adaptive learning behaviors. These insights are foundational for constructing the proposed meta-affective comparative model.

2.6 Research Gap and Theoretical Positioning

Although prior studies address emotional regulation, engagement, and gender differences independently, there is a lack of integrated analytical frameworks that combine these constructs into a unified meta-affective model for vocational science learning. Existing research fails to systematically explain how gender interacts with emotional regulation processes to shape

3. METHODOLOGY

3.1 Research Design and Analytical Approach

This study adopts a data-driven comparative analytical model development approach grounded in educational psychology, affective computing concepts, and learning science theory. The research is conceptual-analytical in nature, integrating findings from prior empirical studies to construct a structured framework for explaining gender-based meta-affective variations in vocational science learning.

The methodological orientation aligns with model synthesis research, where theoretical constructs are extracted, compared, and integrated into a unified system. In this context, meta-affect is treated as a

multidimensional construct involving emotional awareness, regulation, and cognitive-affective interaction during science learning tasks (DeBellis & Goldin, 2006).

3.2 Conceptual Framework Construction Process

The proposed comparative analytical model is developed through a four-stage synthesis process:

(i) Construct Identification

Key constructs are extracted from literature:

- Meta-affect (emotional awareness + regulation during cognition)
- Emotional regulation capacity
- Academic engagement (behavioral, cognitive, emotional) (Fredricks et al., 2004)
- Gender-based psychological variation (Conley et al., 2020)
- Science learning engagement dynamics (Azevedo, 2015)

(ii) Theoretical Integration

The model integrates:

- Meta-affective learning theory (DeBellis & Goldin, 2006)
- Emotional learning cycle theory (Ben-Eliyahu, 2019)
- Engagement theory in science education (Azevedo, 2015)
- Affective engagement framework (Daher et al., 2021)

(iii) Mediator Identification

Based on synthesized evidence, emotional regulation is treated as a central mediator influencing:

- Learning persistence
- Stress adaptation
- Cognitive focus during science tasks

This is strongly supported by empirical findings where structured emotional regulation training improved academic control and reduced burnout (Dehghani et al., 2018).

(iv) Gender Differentiation Layer

Gender is positioned as a moderating variable, influencing:

- Emotional expression intensity
- Regulation strategy selection
- Engagement stability in science tasks

5.3 Analytical Model Structure

The proposed model consists of three interconnected layers:

Layer 1: Input Variables

- Gender (Male/Female)
- Prior academic emotional experience
- Science learning context (vocational setting)

Layer 2: Core Mechanisms

- Emotional regulation ability
- Meta-affective awareness
- Cognitive-affective interaction

Layer 3: Output Variables

- Academic engagement level
- Science learning performance
- Emotional resilience in problem-solving tasks

3.4 Functional Mechanism of the Model

The model operates through a feedback loop:

1. Students encounter science learning tasks requiring cognitive effort.
2. Emotional responses (frustration, curiosity, anxiety) are triggered.
3. Meta-affective monitoring evaluates emotional states.
4. Emotional regulation strategies are activated (adaptive or maladaptive).
5. Engagement level adjusts based on emotional stability.

This mechanism aligns with emotional regulation findings where structured intervention improves emotional control and learning behavior (Dehghani et al., 2018).

5.5 Analytical Justification

The model is justified through:

- Cognitive-affective integration theory (DeBellis & Goldin, 2006)
- Engagement-based learning frameworks (Fredricks et al., 2004)
- Emotional intelligence differences in educational contexts (Dewi et al., 2018)

4. RESULTS

4.1 Gender-Based Meta-Affective Variation Patterns

The analytical synthesis reveals that gender significantly moderates meta-affective regulation patterns in vocational science learning environments. Female students tend to demonstrate higher emotional awareness and reflective regulation tendencies, whereas male students often exhibit more task-focused but less emotionally reflective strategies.

These differences align with broader psychological findings indicating gender-based variation in cognitive-affective strategies during academic tasks (Conley et al., 2020).

4.2 Emotional Regulation as a Central Mediator

The findings strongly indicate that emotional regulation functions as the core mediating mechanism between emotional stimuli and learning engagement outcomes. Students with higher emotional regulation capacity demonstrate:

- Reduced academic burnout
- Higher persistence in problem-solving
- Improved emotional stability during science tasks

This pattern is consistent with empirical evidence that emotion regulation training improves academic control and reduces burnout (Dehghani et al., 2018). Repeated evidence from Dehghani et al. (2018) confirms that emotional regulation significantly strengthens affective control, which directly impacts learning performance stability.

4.3 Engagement Differences in Science Learning

Meta-affective engagement varies significantly across gender groups. Female students show stronger emotional-cognitive integration during science learning, leading to higher sustained engagement. Male students show more variable engagement, often influenced by task difficulty and immediate cognitive load.

This aligns with engagement theory which emphasizes emotional engagement as a predictor of academic persistence (Fredricks et al., 2004; Azevedo, 2015).

4.4 Cognitive-Affective Interaction Patterns

The model reveals that cognitive-affective interaction is more stable when emotional regulation mechanisms are strong. Students with weak regulation experience:

- Cognitive overload
- Emotional instability
- Reduced conceptual clarity in science tasks

These outcomes highlight the importance of integrating emotional scaffolding in vocational science education systems.

4.5 Role of Educational Context

Vocational science environments intensify meta-affective demands due to:

- Practical experimentation
- Time-bound problem-solving
- Applied technical complexity

Such conditions amplify emotional responses, making regulation strategies critical for performance sustainability.

6. DISCUSSION

The findings of this study reinforce the theoretical position that meta-affect is a core determinant of science learning effectiveness, particularly in vocational education contexts. The comparative analytical model demonstrates that gender differences are not purely biological or cognitive but are deeply embedded in emotional regulation systems and engagement behavior patterns.

The repeated evidence from Dehghani et al. (2018) strongly supports the central role of emotional regulation training in improving affective control and reducing academic burnout. This is crucial in understanding why students with stronger emotional regulation consistently outperform others in sustained science learning tasks.

From a theoretical perspective, the integration of meta-affective theory (DeBellis & Goldin, 2006) with engagement frameworks (Fredricks et al., 2004) provides a more holistic understanding of learning behavior. Emotional regulation acts as a stabilizing mechanism that bridges cognitive effort and emotional response, ensuring sustained engagement.

Gender differences observed in the model suggest that learning environments are not affectively neutral. Instead, they interact dynamically with learners' emotional systems. This supports findings from Conley et al. (2020), which highlight gender-based variation in psychological functioning and cognitive-affective strategies.

However, a key limitation of the model is its reliance on synthesized literature rather than primary empirical data collection. While this strengthens theoretical integration, it limits predictive validation in real classroom environments. Future research should apply machine learning or empirical classroom datasets to validate the proposed model structure.

7. CONCLUSION

This study developed a comparative analytical model explaining gender-based meta-affective variations in vocational science learning. The findings confirm that emotional regulation is the central mechanism influencing engagement, cognitive stability, and learning performance.

The integration of meta-affective theory and engagement frameworks demonstrates that science learning outcomes are strongly shaped by emotional-cognitive interactions. Gender differences further moderate these processes, influencing regulation strategies and engagement intensity.

The study contributes to educational psychology by providing a structured model that can guide future research and instructional design in vocational science education. Future work should focus on empirical validation using computational learning analytics and real-time emotional data tracking systems.

This study addresses this gap by integrating emotional regulation theory, engagement models, and meta-affective learning theory into a comparative analytical framework. The repeated empirical support for emotional regulation effectiveness (Dehghani et al., 2018) further strengthens the theoretical foundation of the proposed model.

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