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Latent Profile Analysis of Student Engagement in STEM-Integrated Calculus Education for Character Development and Academic Achievement: A Study Toward SDG 4 in Indonesian Higher Education

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Abstract: This study employed Latent Profile Analysis (LPA) to investigate engagement patterns among Indonesian university students (N = 81) in a calculus course integrated with STEM through engineering case studies and digital tools. A cross-sectional design using a multidimensional engagement questionnaire identified three distinct profiles: Highly Engaged Digital Learners (22.20%), Minimally Engaged Learners (3.70%), and Moderately Engaged Learners Requiring Support (74.10%). ANOVA results revealed that Highly Engaged Digital Learners achieved significantly superior calculus performance (mean score = 89.70) compared to other profiles (mean difference = 17.30 points, $p < 0.001$). MANOVA further indicated that this group demonstrated substantially greater development of character virtues, including perseverance, intellectual honesty, and collaborative ethics (all $p < 0.001$). The findings confirm that STEM-integrated calculus education, when effectively engaging students, serves a dual pedagogical function, simultaneously advancing technical competencies and ethical reasoning. This highlights its transformative potential in fostering holistically developed professionals, aligning with Sustainable Development Goal 4 (Quality Education). Strategic educational responses should include early engagement profiling and targeted support to maximize these benefits.

Keywords: Calculus learning; Character development; Digital learning engagement; Latent profile; STEM

Introduction

Indonesia's tertiary education sector stands at a critical juncture, urgently needing to produce professionals who possess not only specialized STEM (Science, Technology, Engineering, and Mathematics) skills but also a solid ethical foundation to navigate complex technological landscapes (Borrego & Henderson, 2014; Hess & Fore, 2017). This dual demand aligns with global educational shifts towards holistic development, emphasizing that technical prowess must be coupled with responsible innovation (Council, 2014). In response, integrated STEM education has emerged as a promising pedagogical framework, aiming to bridge disciplinary silos and connect abstract concepts to real-world problem-solving (English, 2016; Thibaut et al., 2018).

However, the effective implementation of STEM in classrooms, particularly in resource-variable contexts like Indonesia, faces significant challenges. These include the provision of accessible and contextually relevant project support materials (Caruth, 2016; Zulirfan & Yennita, 2022), as well as broader constraints related to instructional time, teaching materials, and

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institutional infrastructure (Effendi et al., 2025). Despite these hurdles, evidence suggests that when successfully enacted—for instance, through problem-based learning (PBL) models integrated with STEM—such approaches can significantly enhance students' critical thinking skills and transform the learning process (Gusman et al., 2023; Monika et al., 2023; Taqiyyah et al., 2023; Freeman et al., 2014). Calculus, a foundational subject in engineering and computing, traditionally emphasizes procedural mastery, often overlooking its potential for instilling professional character traits such as meticulousness, honesty, and determination (Bressoud, 2015; Kelley & Knowles, 2016).

Contemporary educational reforms advocate for integrated STEM teaching, which embeds mathematical principles within practical, real-world scenarios, thereby transforming mathematics into a tool for developing the structured reasoning necessary for ethical decision-making in technology-driven fields (English, 2016; Usher & Barak, 2024).

Despite this recognized potential, empirical research examining how STEM-integrated mathematics learning concurrently influences both academic performance and character development remains scarce, particularly within the Indonesian context (Holik et al., 2023). Previous studies on student engagement have predominantly utilized variable-centered approaches, which may overlook the heterogeneous nature of student populations in STEM education (Bergman & Trost, 2006; Spurk et al., 2020). This study addresses these gaps by applying a person-centered methodological approach. The novelty of this research lies in its use of Latent Profile Analysis (LPA) to identify distinct, holistic engagement typologies among Indonesian calculus students, and in its simultaneous investigation of the relationship between these typologies and two critical outcomes: academic achievement and character virtue development. Understanding these profiles is vital for designing equitable and effective pedagogical interventions that cater to diverse student needs, ultimately contributing to a skilled and principled Indonesian workforce.

Therefore, this study explicitly investigates the patterns of student engagement that surface in STEM-integrated calculus courses, how these patterns are associated with calculus performance, and to what extent this integrated approach promotes character development alongside technical skill acquisition. Engagement in this context is operationalized through four key dimensions derived from the literature: digital literacy, motivation, self-efficacy, and learning strategies (Holik et al., 2023; Ng, 2012).

Method

This research was structured as an explanatory sequential mixed-methods design (QUAN → QUAL) (Creswell & Plano Clark, 2023; Marsh et al., 2009). This design involved collecting and analyzing quantitative data first, followed by qualitative data collection to explain and elaborate on the quantitative findings. The integrated flow of the research procedure is presented in Figure1.

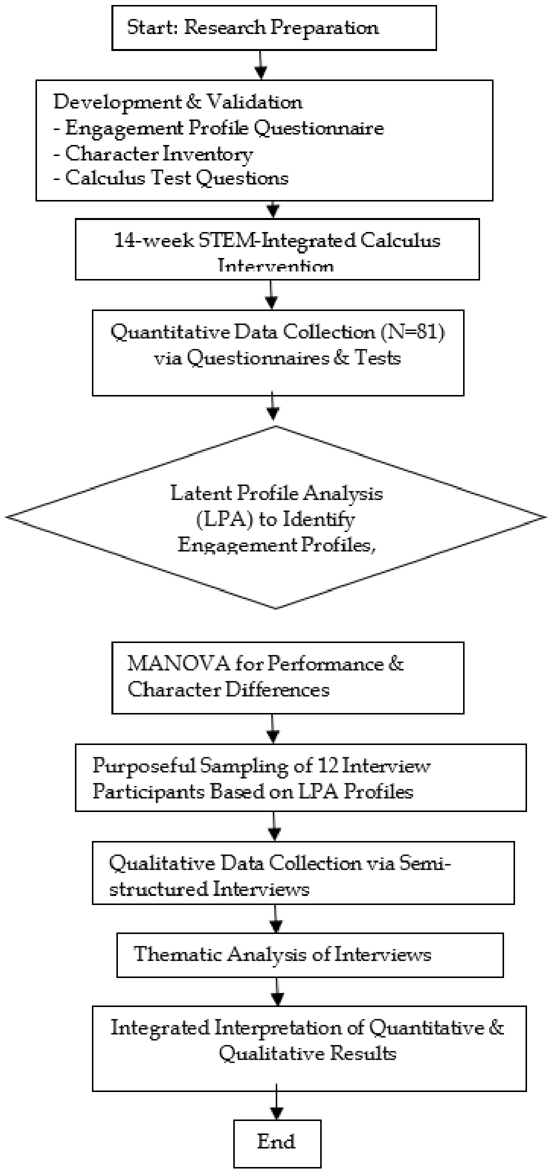

Figure 1. Research Flowchart of the Explanatory Sequential Mixed-Methods Design

Participants

The participant group consisted of 81 undergraduate students purposively sampled from three engineering majors—Informatics (n=27), Electrical (n=28), and Industrial Engineering (n=26)—across three

Indonesian universities. The sample comprised 53% male and 47% female participants, all enrolled in a mandatory calculus course enhanced with STEM pedagogy. This study received formal ethical approval from the Research Ethics Committee of Universitas Putra Indonesia "YPTK" Padang (Approval No: 030/LPPM.UPI-YPTK/SPD.P/HS. V/XI/2025). All participants provided voluntary written informed consent.

Instruments and Intervention

Quantitative Instruments.

Data were gathered using a triangulation of instruments. The primary instrument was the *STEM Engagement Profile Questionnaire*, developed by synthesizing Ng (2012) digital literacy framework and Holik et al. (2023) multidimensional engagement construct. The final questionnaire comprised 20 items across four validated subscales: Digital Literacy (5 items), Motivation (5 items), Self-Efficacy (5 items), and Learning Strategies (5 items). Content validation by three STEM education experts yielded a Content Validity Index (CVI) > 0.85 for all items. Pilot testing with 30 students from similar programs confirmed high reliability, with Cronbach's alpha coefficients ranging from 0.82 to 0.88 for the subscales and 0.88 for the total scale.

Academic performance was measured using a standardized *Calculus Performance Assessment* covering core differential and integral calculus topics aligned with the course objectives. Character development was assessed using a validated *Character Development Inventory* ($\alpha = 0.85$), which measured four key professional virtues: Perseverance, Intellectual Honesty, Collaborative Ethics, and Precision.

Pedagogical Intervention

The study implemented a 14-week calculus course explicitly redesigned around STEM integration principles (English, 2016). The intervention moved beyond traditional lecture-based methods to include: (1) engineering case studies with ethical dimensions (e.g., optimizing renewable energy systems while considering environmental trade-offs), (2) collaborative team projects requiring mathematical modeling of real-world problems, (3) extensive use of digital visualization tools such as GeoGebra for dynamic concept exploration and simulation (see Figure 2), and (4) guided reflective journaling prompts designed to help students connect technical problem-solving with professional character growth.

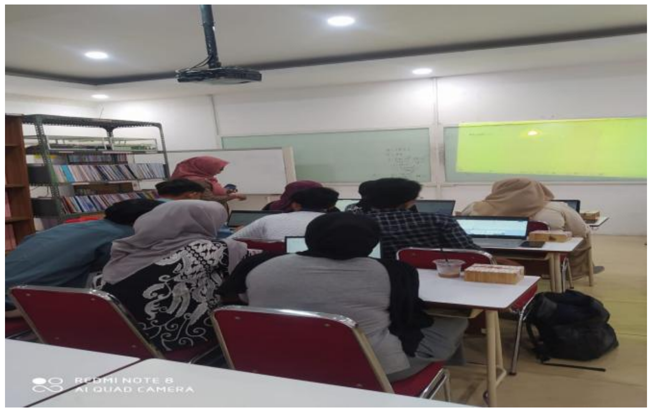

Figure 2. Student Collaborative Work Using Digital Tools

Data Analysis

The data analysis followed the sequential logic of the research design.

Phase 1: Quantitative Analysis. Quantitative analysis proceeded in two sequential steps. First, Latent Profile Analysis (LPA) was conducted using Mplus version 8.0 to identify homogeneous, latent subgroups of students based on their scores across the four engagement dimensions. Model selection adhered to established guidelines (Spurk et al., 2020), with fit assessed using the Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC), sample-size adjusted BIC (aBIC), and entropy. The three-profile solution demonstrated optimal fit with high classification accuracy (entropy = 0.86). Second, once profiles were established, differences among them in calculus performance and character development scores were analyzed using one-way Analysis of Variance (ANOVA) and Multivariate Analysis of Variance (MANOVA), respectively, followed by post-hoc Tukey HSD tests for pairwise comparisons.

Phase 2: Qualitative Analysis. Following the quantitative phase, the LPA results directly informed the qualitative data collection. A subset of 12 participants was purposefully selected (4 from each of the three identified engagement profiles) for in-depth, semi-structured interviews. The interview protocol was designed to explore the underlying reasons for the quantitative patterns, probing participants' experiences with the STEM-integrated activities, perceived drivers of their engagement, and reflections on character development. All interviews were audio-recorded, transcribed verbatim, and analyzed using thematic analysis following the six-phase approach outlined by Braun & Clarke (2006). This qualitative analysis provided explanatory depth, contextualized the statistical profiles, and uncovered the mechanisms through which the integrated pedagogy influenced both learning and character outcomes.

Integration

In the final stage, findings from both phases were synthesized. The qualitative themes were used to explain, illustrate, and interpret the quantitative results, fulfilling the explanatory purpose of the sequential design and leading to a more comprehensive understanding of the research phenomena.

Results and Discussion

Engagement Profile Identification

LPA based on four engagement dimensions revealed three distinct profiles (Table 1). Profile 1, labeled *Highly Engaged Digital Learners* (22.20%), demonstrated consistently high scores across all dimensions. Profile 2, labeled *Minimally Engaged Learners* (3.70%), showed very low engagement. Profile 3, labeled *Moderately Engaged Learners Requiring Support* (74.10%), exhibited moderate engagement with significant room for growth, particularly in digital literacy and learning strategies.

Academic Performance Differences

One-way ANOVA revealed significant differences in calculus performance among the profiles ($F(2, 78) = 572.00$, $p < 0.001$, $\eta^2 = 0.60$). Post-hoc Tukey tests indicated that Highly Engaged Digital Learners significantly outperformed both other groups (all $p < 0.001$). The mean difference between the Highly Engaged and Minimally Engaged profiles was 17.30 points. Performance details are shown in Table 2.

Table 1. Engagement Profile Characteristics and Distribution

Dimension	Highly Engaged Digital Learners (n=18, 22.20%)	Minimally Engaged Learners (n=3, 3.70%)	Moderately Engaged Learners Requiring Support (n=60, 74.10%)
Digital Literacy	4.15	1.13	3.25
Motivation	4.56	1.00	3.52
Self-Efficacy	4.19	1.00	3.59
Learning Strategies	4.36	1.00	3.44

Note: All scores are on a 5-point scale

Table 2. Calculus Performance by Engagement Profile

Profile	N	Mean	SD	Category
Highly Engaged Digital Learners	18	89.70	6.50	Excellent
Minimally Engaged Learners	3	72.40	8.20	Satisfactory
Moderately Engaged Learners Requiring Support	60	76.10	7.90	Needs Improvement

Character Development Outcomes

A one-way MANOVA was conducted to examine profile differences across the four-character virtues. The multivariate test was significant (Wilks' $\Lambda = 0.25$, $F(8, 150) = 35.18$, $p < 0.001$). Subsequent univariate ANOVAs, summarized in Table 3, showed significant differences for all virtues (all $p < 0.001$). Post-hoc comparisons confirmed that Highly Engaged Digital Learners reported significantly stronger character development than the other two profiles.

Table 3. Character Development by Engagement Profile

Character Trait	Highly Engaged Digital Learners	Minimally Engaged Learners	Moderately Engaged Learners Requiring Support	F-value
Perseverance	4.32	2.89	3.45	42.31***
Intellectual Honesty	4.28	2.67	3.51	38.94***
Collaborative Ethics	4.15	2.78	3.38	35.62***
Precision	4.41	2.92	3.56	46.78***

**$p < 0.001$*

Integrated Discussion

This study establishes that calculus instruction incorporating STEM principles through case-based and collaborative methods can simultaneously cultivate mathematical proficiency and nurture professional character attributes. This dual outcome aligns with integrated STEM frameworks that advocate for authentic, problem-based learning to develop both cognitive and affective domains (Honey et al., 2014; Thibaut et al., 2018). The use of LPA, a person-centered approach, effectively uncovered the heterogeneous engagement patterns within the student population, a nuance often masked by traditional variable-centered analyses (Bergman & Trost, 2006; Spurk et al., 2020). This methodological choice is substantiated by research advocating for person-oriented analyses to understand the complex, subgroup dynamics in educational settings (Morin et al., 2016). The robust association observed between the *Highly Engaged Digital Learner* profile and superior outcomes in both domains underscores the critical role of holistic engagement, consistent with comprehensive models of student engagement that link cognitive, behavioral, and affective engagement to positive academic and developmental outcomes (Fredricks et al., 2004; Lawson & Lawson, 2013).

The qualitative insights provided explanatory depth for these quantitative relationships. For instance, one highly engaged student noted, "*Solving optimization problems for sustainable energy systems required both mathematical precision and ethical consideration of environmental impact. This changed how I approach engineering problems—not just technically, but responsibly.*" This reflection demonstrates how the integrated STEM methodology created authentic contexts for ethical deliberation, a process central to situated learning theory where knowledge is constructed through participation in meaningful, community-based practices (Lave & Wenger, 1991). Furthermore, it aligns with constructivist principles that emphasize social interaction and real-world problem-solving as key to internalizing values and complex concepts (Vygotsky, 1978). The significant digital literacy gap between profiles reinforces Ng (2012) assertion that mere technological access is insufficient for meaningful learning engagement. This finding echoes broader calls in educational technology research, which emphasize that structured digital literacy support, pedagogically integrated with content, is essential for equitable learning outcomes (Bernard et al., 2014; Sokolowski et al., 2015), a point particularly critical in diverse Indonesian classrooms with varying levels of technological preparedness.

The pronounced character development in the highly engaged group supports the hypothesis that deep, active engagement with complex mathematical problem-solving intrinsically fosters virtues like perseverance, intellectual honesty, and collaborative ethics. This process mirrors the development of a "growth mindset" and self-efficacy through mastery experiences (Howard et al., 2021; Martin & Rimm-Kaufman, 2015). These character traits are directly transferable to professional engineering and computing practice, where ethical reasoning and resilience are paramount (Hess & Fore, 2017; Sanders, 2009). However, the large proportion of students (74.10%) in the *Moderately Engaged Learners Requiring Support* profile indicates a pressing need for scalable, targeted interventions. This majority group, which exhibits moderate engagement but has clear development potential, represents a critical leverage point for improving overall educational quality. Targeted strategies should include the early identification of engagement profiles via short diagnostic surveys, the implementation of differentiated instruction to bolster digital competencies and self-efficacy (Sinatra et al., 2015), and explicit mentoring that links technical problem-solving to professional ethics (Prastika et al., 2024). Such approaches are supported by literature on effective STEM pedagogy, which recommends responsive teaching and support structures to engage a broader range of learners (Freeman et al., 2014; Stohlmann et al., 2012).

A notable limitation of this study is the very small size of the *Minimally Engaged Learners* profile (n=3), which affects the statistical stability and generalizability of findings specific to this group. While LPA can identify small, distinct subgroups, interpretations regarding this profile should be made with caution. Future research should involve larger, multi-institutional, and longitudinal samples to validate these engagement profiles across different contexts and to investigate the causal effects of tailored pedagogical interventions based on LPA classifications. Longitudinal designs could trace how engagement profiles evolve over time and in response to specific support mechanisms (Wang & Degol, 2014). Expanding this research to other STEM disciplines within the Indonesian higher education context would also test the transferability of the identified profiles and intervention strategies (Borrego & Henderson, 2014).

Conclusion

This study confirms that student engagement profiles in STEM-integrated calculus are significant indicators of both academic achievement and character development. The identification of three distinct learner categories—Highly Engaged Digital Learners, Minimally Engaged Learners, and Moderately Engaged Learners Requiring Support—provides a nuanced framework for differentiated teaching that concurrently addresses intellectual and ethical educational goals. The results reposition calculus from a mere technical hurdle to a formative experience shaping future professionals' analytical and moral reasoning. For Indonesian higher education, these insights underscore the imperative of pedagogical innovations that leverage STEM integration. To foster holistic graduate development, actionable recommendations include: embedding ethical dilemmas within calculus problems through engineering scenarios; providing professional development for mathematics lecturers in integrated STEM and character pedagogy; designing assessment rubrics that measure both mathematical skill and demonstrated character virtues; and implementing early engagement profiling to enable timely, personalized student support. By adopting such strategies, institutions can better equip graduates to drive technological advancement while upholding ethical responsibility, directly contributing to the aims of Sustainable Development Goal 4.

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Author Contributions
Conceptualization: D.E. and Z.Z.; Methodology: D.E., Z.Z., and F.Y; Formal analysis: D.E. and M.P.N.; Investigation: D.E., E.H.B., and Firmawati; Resources: Z.Z. and Helmiyanti; Data curation: F.Y. and E.H.B; Writing original draft preparation: D.E; Writing review and editing: Z.Z., F.Y., and M.P.N.; Visualization: D.E. and Firmawati; Supervision: Z.Z; Project administration: D.E. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest
The authors declare no conflict of interest.

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