2026 ASEE ANNUAL CONFERENCE June 21–24, 2026 | Charlotte Convention Center, NC
Host Sponsor UNC Charlotte
Paper ID #52736

Humanizing Engineering Education: Empathy, Engagement, and Self-Efficacy as Pathways to Equity in Learning Design

Prof. Sharon Tettegah, University of California, Santa Barbara

Sharon Tettegah is a Professor at the University of California, Santa Barbara, whose research in engineering education examines empathy, engagement, self-efficacy, and learning preferences as critical dimensions of student learning and success in STEM. Her transdisciplinary scholarship bridges engineering education, educational psychology, artificial intelligence, and ethics, with a sustained focus on equity, inclusion, and human-centered design. She is the author of a The Conversation essay on rethinking engineering education through learning preferences and diversity. Through her research, Tettegah advances scholarly and practical approaches to creating more responsive, inclusive, and effective engineering learning environments.

Dr. EBENEZER LARNYO, University of California, Santa Barbara

Dr. Ebenezer Larnyo's research lies at the intersection of data science, engineering, and health informatics, with a focus on equity and human-centered design. His work integrates machine learning, behavioral theory, and advanced quantitative methods to examine learning processes, technology adoption, and disparities across diverse populations.

Humanizing Engineering Education: Empathy, Engagement, and Self-Efficacy as Pathways to Equity in Learning Design

Sharon Tettegah*, Ebenezer Larnyo
Corresponding Author*: stettegah@ucsb.edu
University of California, Santa Barbara

Abstract

Broadening participation and promoting equity in engineering education remain persistent challenges despite decades of national investment. While traditional diversity efforts have emphasized access and recruitment, emerging evidence highlights the importance of understanding how psychological factors shape engagement and learning preferences. This study examines how empathy, engagement, and self-efficacy predict undergraduate engineering and STEM majors' preferences for curriculum representations across core engineering and physics topics, including static and projectile motion, magnetic forces, and mathematical content such as the Pythagorean theorem. Grounded in a human-centered approach to engineering education, the research investigates how emotional and cognitive factors influence learners' interactions with textual, symbolic, graphical, and pseudo-realistic visual materials. Data were collected from 964 undergraduate students at four U.S. research universities. Participants completed validated measures of affective and cognitive empathy, behavioral, cognitive, and emotional engagement, and self-efficacy, along with a structured survey assessing preferences for 24 curriculum formats. Partial least squares structural equation modeling was used to analyze relationships among six core psychological constructs and instructional representation preferences. Results indicated that cognitive empathy was associated with preferences for structured, abstract representations such as equations and diagrams, whereas affective empathy aligned with emotionally evocative or pseudo-realistic formats. Self-efficacy functioned as a moderator, with higher confidence linked to minimalist or exploratory visuals and lower confidence associated with scaffolded, visually detailed designs. Cognitive and emotional engagement predicted preferences for expressive or immersive visuals, while behavioral engagement was negatively related to passive formats. These findings demonstrate that empathy, engagement, and self-efficacy interact to shape how students engage with instructional representations. By integrating psychological and pedagogical insights, this work advances engineering education and underscores the value of empathy-informed, multimodal design for fostering inclusion, persistence, and deeper learning.

Introduction

Broadening participation and increasing diversity in engineering education remain long-standing challenges in the United States. Despite decades of financial and institutional investment to improve representation among women, students of color, and individuals with disabilities, disparities persist [1, 2, 3]. Although the National Science Foundation [4] reported parity in select disciplines, most engineering fields remain below population representation. The causes of these disparities are complex and multifactorial, often reflecting limited accessibility, sociocultural bias, and insufficient understanding of how psychological factors interact with curriculum design [5, 6]. These disparities are not incidental but reflect the historically exclusionary foundations of engineering education, which has long privileged particular ways of knowing while marginalizing others.

Emerging evidence suggests that understanding diverse learning preferences through psychological dimensions such as empathy, engagement, and self-efficacy may yield new insights into student retention and performance [7, 8, 9]. This study investigates how these dimensions predict preferences for distinct curriculum representations, providing a data-driven foundation for engineering pedagogy [10]. Our research question asks, "What is the relationship of the typologies of curricular preferences with empathy, engagement, and self-efficacy of students in engineering?" This study examines predictors of curriculum preference by exploring the roles of psychological factors, including affective empathy, cognitive empathy, cognitive engagement, behavioral engagement, emotional engagement, and self-efficacy.

Contextual Framework

Building on the broader discourse of inclusive and human-centered engineering education, this research is grounded in the mission and values of the Equity, Culture, and Social Justice in Education Division (ECSJ), which calls for interrogating the structural conditions that shape whose knowledge practices are legitimized in engineering learning environments. ECSJ conceptualizes the engineering classroom as a terrain of struggle and site of possibility, where instructional representations are not neutral artifacts but reflect historically situated norms about ways of knowing. The present study responds to this framing by examining how psychological constructs such as empathy, engagement, and self-efficacy influence learners' preferences for diverse curricular representations across engineering and physics [11], situating curricular design as a site where epistemic access, belonging, and participation are negotiated. This work also engages the mission of the Design in Engineering Education Division (DEED), which promotes innovative and equitable approaches to design learning and emphasizes that effective engineering education must extend beyond technical proficiency to include creativity, empathy, and social responsibility. By exploring affective and cognitive dimensions of learner preference, the study contributes to both divisions' commitments to understanding the human side of engineering education and shaping pedagogy that is technically rigorous and socially responsive to the varied ways students experience and interpret learning [12].

In this study, empathy is operationalized across two distinct but interrelated dimensions: affective empathy, referring to the capacity for emotional attunement and vicarious experience of others' feelings, and cognitive empathy, denoting the ability to understand and take the perspective of another person's mental state. Engagement is conceptualized as a multidimensional construct encompassing behavioral participation in learning tasks, cognitive effort and self-regulation, and emotional connection to the learning environment. Self-efficacy, following Bandura's [13] social cognitive theory, refers to learners' beliefs in their ability to successfully perform academic tasks within engineering contexts. Together, these constructs form the psychological foundation of the human-centered framework guiding this study.

Guided by this commitment to human-centered and equitable engineering education, the study employed a mixed-methods approach to investigate how empathy, engagement, and self-efficacy predict learners' preferences for different curriculum representations. This design was selected to capture the complex interactions between psychological and pedagogical factors that influence learning experiences in technical fields [14]. A large-scale survey of undergraduate students from four research universities was conducted to gather both demographic and psychosocial data, ensuring representation across diverse engineering and STEM disciplines. Quantitative analyses using partial least squares structural equation modeling were used to identify relationships between six latent constructs and visual or textual learning preferences. This approach provided a robust framework for understanding how psychological diversity informs curriculum design and for identifying pedagogical strategies that support inclusion and belonging in engineering education [15].

In addition to its alignment with human-centered and design-oriented engineering education, this work also foundationally centers Equity, Culture, and Social Justice in Education (ECSJ) perspective that conceptualizes the engineering classroom as a terrain of struggle and site of possibility. Within this view, instructional representations are not neutral artifacts but reflect historically situated norms about whose ways of knowing are legitimized in engineering learning environments. By examining how empathy, engagement, and self-efficacy shape learners' preferences for textual, symbolic, and visual representations, this study situates curricular design as a site where epistemic access, belonging, and participation are negotiated. Understanding psychological diversity in representation preferences therefore contributes to efforts to transform engineering classrooms into spaces that affirm multiple epistemologies while disrupting deficit assumptions about learners.

This study takes seriously the ECSJ charge to work toward transforming engineering education communities in becoming more grounded in liberatory struggles. When psychological diversity in representation preferences goes unrecognized, curricula implicitly reproduce hierarchies of knowing, privileging abstract, decontextualized reasoning as the unmarked norm of engineering competence while rendering other ways of engaging technically invisible or deficient. Attending to how empathy and affect shape learning is not merely a pedagogical refinement but a form of resistance to the ableist, deficit-oriented epistemologies that have historically structured engineering education.

In this study, empathy is conceptualized as affective (emotional attunement) and cognitive (perspective-taking) dimensions; engagement as behavioral, cognitive, and emotional participation in learning; and self-efficacy as learners' confidence in their academic capability within engineering contexts.

Methodology

To operationalize this design, participants were recruited from multiple institutions to ensure a diverse and representative sample of students engaged in engineering and related STEM programs.

Participants

Participants were recruited from four major research universities in the Midwest, Southwest, and West Coast regions of the United States. The selection strategy ensured a diverse and representative sample of undergraduate students enrolled in engineering courses. A total of 964 undergraduate participants completed the study. Demographic data were collected on gender, race or ethnicity, academic level, and disciplinary affiliation, enabling analysis of how individual differences may relate to empathy, engagement, and self-efficacy. This diversity of participants provided a comprehensive foundation for understanding how psychological and affective factors influence learning preferences across varied engineering contexts [10, 12, 16]. Our sample included 30% Latina/o, 24% White, 20% Asian/Pacific Islanders, 9% African American, and 17% Bi-Racial and Other.

Participants represented multiple engineering disciplines, including mechanical, electrical, civil, and computer engineering, along with students from physics and mathematics. Among the 964 participants, the largest disciplinary representation was in mechanical engineering (approximately 28%), followed by electrical engineering (22%), computer engineering (19%), civil engineering (14%), and students from physics and mathematics programs (17%). This distribution reflects the curricular emphases of the four participating research universities and provides a sufficiently varied disciplinary base to examine how psychological characteristics interact with representation preferences across technical domains.

Measures

A structured online questionnaire was designed and distributed via Qualtrics, collecting responses from 964 university students across diverse engineering and STEM programs within the United States of America. Participants rated their preference for 24 distinct curriculum representations derived from course materials, including text descriptions, equations (abstract), line illustrations (abstract), schematic illustrations (graphical), and pseudo-realistic images (graphical). Although all representations are abstract, some demonstrate actual simulated representation through graphical imaging, as opposed to equations.

All 964 students were given psychosocial instruments to measure high to low affective and cognitive empathy, cognitive, behavioral, and emotional engagement, and self-efficacy.

The study used validated instruments to assess empathy, engagement, and self-efficacy, along with a custom-developed survey to measure preferences for curriculum representations. These measures were selected to capture both affective and cognitive dimensions of learning, aligning with the study's theoretical framework and established research in engineering education and psychology. Empathy Measures: Empathy was assessed using two established instruments. The Interpersonal Reactivity Index [17] measured affective and cognitive empathy through subscales such as empathic concern and perspective taking. In addition, the Basic Empathy Scale [18] provided a complementary assessment of students' emotional and cognitive responsiveness to others. Together, these tools provided a multidimensional understanding of how empathy influences learning preferences and engagement in engineering contexts.

Engagement Measures: Engagement was examined across three domains: behavioral, cognitive, and emotional, using items adapted from the Student Engagement Questionnaire [19]. This measure captured students' participation, mental effort, and affective connection to learning tasks. Behavioral engagement items reflected active involvement, cognitive engagement items measured depth of processing and self-regulation, and emotional engagement items assessed interest, enjoyment, and sense of belonging during learning activities.

Self-Efficacy Measures: Academic self-efficacy was measured using validated scales from the Patterns of Adaptive Learning Scales [20] and the Mathematics Achievement and Self-Efficacy Scale [21] These instruments evaluated learners' confidence in performing academic tasks and solving problems across disciplinary contexts. Self-efficacy served as both a predictor and a moderator in the study, helping explain variations in preferences for different visual and textual representations.

User Preference Survey: The user preference instrument was designed by the research team through iterative focus groups and data mining of course materials. The survey included 24 curriculum representations, categorized by modality (text, equations, line illustrations, schematic images, and pseudo-realistic graphics). Each item prompted participants to rate their preference on a five-point Likert scale ranging from "strongly dislike" to "strongly prefer." These representations were selected to capture a range of abstraction and realism, enabling an analysis of how psychological characteristics influence visual and textual learning choices.

Together, these instruments provided a comprehensive basis for examining the relationships among empathy, engagement, self-efficacy, and curriculum representation preferences. This multidimensional measurement framework ensured that the study addressed both the affective and cognitive factors central to inclusive and human-centered engineering education.

Data Analyses

Data were analyzed using SmartPLS 4, applying Partial Least Squares Structural Equation Modeling (PLS- SEM) to examine relationships among empathy, engagement, self- efficacy, and curriculum representation preferences. This approach was selected because it is well suited for exploring complex predictive relationships between latent psychological constructs and observable outcomes in educational research. PLS- SEM enables the simultaneous estimation of measurement and structural models, allowing robust evaluation of construct reliability and the strength of hypothesized relationships.

Before testing the structural model, measurement model assessments were conducted to ensure validity and reliability. Convergent validity was verified through factor loadings, average variance extracted (AVE), and composite reliability. Discriminant validity was examined using the Fornell- Larcker criterion and cross- loading analysis. Items with factor loadings below the accepted threshold of 0. 60 were excluded to maintain model integrity. All constructs demonstrated acceptable internal consistency and validity according to established criteria.

The structural model was then analyzed to identify the strength and significance of relationships among the six latent constructs: affective empathy, cognitive empathy, behavioral engagement, cognitive engagement, emotional engagement, and self- efficacy. Path coefficients (β), t- statistics, and p- values were computed using bootstrapping procedures with 5,000 resamples to estimate standard errors and test the significance of hypothesized paths. A relationship between constructs was considered statistically significant when $p < .05$ ($t > 1.96$) or highly significant when $p < .01$ ($t > 2.58$). Path coefficients closer to + 1 indicated strong positive relationships, while coefficients near zero were interpreted as weak or non-significant associations.

Model fit indices, including the standardized root mean square residual (SRMR) and coefficient of determination (R^2), were examined to assess the overall quality of the model. SRMR values below 0. 08 indicated an acceptable fit between the observed and predicted data, and R^2 values provided insight into the proportion of variance explained by the predictors. Multicollinearity was evaluated through variance inflation factors (VIF), with all values falling below the threshold of 5.0, confirming that collinearity was not a concern.

The combination of these analyses provided both statistical rigor and theoretical insight into how empathy, engagement, and self- efficacy interact to influence students' preferences for textual and visual curriculum representations. This analytical strategy provided a comprehensive foundation for interpreting the results and drawing implications for inclusive, psychologically responsive design in engineering education.

Results and Discussion

The results are organized into five curriculum domains: Static, Projectile, Motion, Magnetic, and Pythagorean Theorem. Each section integrates results and interpretation to explain how empathy, engagement, and self-efficacy shape learners' preferences for textual and visual curriculum representations. Across all domains, six psychological predictors were examined: affective empathy, cognitive empathy, behavioral engagement, cognitive engagement, emotional engagement, and self-efficacy. Understanding how these psychological predictors operate across content domains is therefore not simply a technical exercise but a step toward identifying where curricular norms may be inadvertently privileging some learners over others.

Static

Static representations were presented in six formats. For text descriptions, no significant predictors were found (all $ps > .05$), indicating that learners' preferences for textual representations may be relatively stable across varying levels of empathy, engagement, or self-efficacy.

In the equations condition, cognitive empathy was a significant positive predictor ($\beta = .128$, $p < .001$). This suggests that learners who better understand others' perspectives are more inclined to appreciate equation-based representations, possibly because their abstract yet structured nature aligns with perspective-taking and logical reasoning.

In the case of abstract free-body images, cognitive engagement had a significant adverse effect ($\beta = –.095$, $p = .010$). This suggests that learners who are more mentally invested in processing and elaborating information may find abstract visuals less accessible or more cognitively taxing, and may prefer formats that offer more concrete cues.

The line illustration image yielded the most diverse pattern of significant predictors. Affective empathy ($\beta = .216$, $p < .001$) and emotional engagement ($\beta = .092$, $p = .033$) were positively associated with preference, whereas cognitive empathy ($\beta = –.078$, $p = .023$) had an adverse effect. This suggests that emotionally attuned learners may resonate with line illustrations because of their clarity and expressive form. In contrast, those high in cognitive empathy may prefer more conceptually dense representations, such as equations.

For pseudo-realistic images, both cognitive empathy ($\beta = –.162$, $p < .001$) and behavioral engagement ($\beta = –.103$, $p = .035$) were significant negative predictors. This finding suggests that learners who are more action-oriented or skilled at perspective-taking may view pseudo-realistic images as unnecessarily embellished or distracting from core learning objectives.

In summary, Table 1 presents the results for static visual representations. Learners with higher cognitive empathy preferred equation-based visuals ($\beta = .128$, $p < .001$), suggesting that perspective-taking aligns with structured reasoning. Cognitive engagement negatively predicted preference for abstract free-body images ($\beta = –.095$, $p = .010$), indicating that mentally active learners may find such visuals too abstract. Affective empathy and emotional engagement positively influenced preference for line illustrations ($\beta = .216$, $p < .001$; $\beta = .092$, $p = .033$), whereas cognitive empathy negatively predicted this format ($\beta = –.078$, $p = .023$). Behavioral engagement negatively predicted preference for pseudo-realistic images ($\beta = –.103$, $p = .035$).

Table 1. Static visual representations of student preferences.

Predictor	**Text Description**	**Equations**	**Abstract Free Body Image**	**Line Illustration Image**	**Pseudo-realistic Image**
Affective Empathy (AEm)	ns	ns	ns	Sig (+)	ns
Behavioral Engagement (BE)	ns	ns	ns	ns	Sig (-)
Cognitive Empathy (CEm)	ns	Sig (+)	ns	Sig (-)	Sig (-)
Cognitive Engagement (CEn)	ns	ns	Sig (-)	ns	ns
Emotional Engagement (EE)	ns	ns	ns	Sig (+)	ns
Self-Efficacy (SEF)	ns	ns	ns	ns	ns

Note. ns = not significant ($p \geq .05$); + = significant positive relationship ($p < .05$); – = significant negative relationship ($p < .05$).

Discussion. The pattern of results highlights that learner characteristics interact meaningfully with visual representation formats. Cognitive empathy consistently emerged as a significant predictor, but in different directions across modalities: positively for equations and negatively for line illustrations and pseudo-realistic images. This suggests that individuals skilled in understanding others' mental states may prefer formats that are abstract and precise but may find stylized or overly interpretive visuals less appealing or less informative.

Similarly, engagement dimensions influenced preferences selectively. Emotional engagement positively predicted preference for line illustrations, potentially due to their emotionally expressive or relatable aesthetic. Behavioral engagement, however, was negatively associated with preference for pseudo-realistic images, possibly indicating that more active learners prefer less visually complex formats that allow quicker assimilation of key information. This pattern aligns with findings by Alzayed [22], who demonstrated that behaviorally active engineering learners tend to favor streamlined, task-relevant representations over visually embellished formats.

Interestingly, text descriptions, despite being a conventional format, were not significantly influenced by any of the psychological variables. This may point to a baseline preference or habituation effect, where textual information is viewed as a default or neutral option, regardless of individual traits.

The results underscore the importance of matching visual design with learner profiles, especially in domains such as STEM or design education, where visual representations are integral. Understanding which psychological traits align with specific visual formats can help educators develop adaptive and inclusive curricula that cater to diverse learners.

Projectile

The projectile model examined how six learner characteristics influenced preferences for nine different types of projectile representations, ranging from text-based to highly visual and interactive formats. These characteristics included affective empathy, behavioral engagement, cognitive empathy, cognitive engagement, emotional engagement, and self-efficacy.

Table 2 presents the results for text descriptions. Self-efficacy was the only significant predictor, showing a negative association ($\beta = -.179$, $p < .001$), suggesting that learners who feel more confident in their capabilities tend to prefer non-textual representations. A similar pattern was observed for equations, where both affective empathy ($\beta = -.190$, $p < .001$) and self-efficacy ($\beta = -.160$, $p < .001$) were negatively associated with preference.

For more dynamic or visual representations, such as GIFs, several positive effects emerged. Cognitive empathy ($\beta = .108$, $p = .007$) and self-efficacy ($\beta = .143$, $p < .001$) positively predicted preference. At the same time, behavioral engagement was negatively associated (β = –.144, p = .046), suggesting that learners who are more behaviorally active may view GIFs as insufficiently interactive.

In the case of pseudo-realistic images, cognitive empathy (β = .125, p < .001) and cognitive engagement (β = .080, p = .057) showed a preference trend. In contrast, for pseudo-realistic images with force overlays, affective empathy (β = .122, p < .001), cognitive engagement (β = –.167, p < .001), and self-efficacy (β = .135, p = .002) were all significant.

Line illustration images, both with and without force cues, had minimal significant predictors. Only self-efficacy negatively predicted preference for line + force images (β = –.083, p = .013), which may suggest that more self-confident learners prefer representations that are more abstract or less scaffolded.

For abstract free body images, affective empathy (β = –.153, p < .001) and behavioral engagement (β = –.088, p = .049) were negative predictors, suggesting that learners who are emotionally sensitive or behaviorally engaged may find such representations too abstract or disconnected.

Finally, for interactive simulations, three variables showed significant positive effects: affective empathy (β = .182, p < .001), cognitive empathy (β = .125, p < .001), and self-efficacy (β = .152, p < .001). These findings suggest that interactive representations appeal most to learners who are empathetic and confident, aligning with prior research that interactive modalities benefit learners who are both cognitively and emotionally engaged. This is further supported by Anwar, et al. [8], whose meta-analysis found that both affective and cognitive engagement significantly predict learner responsiveness to immersive and interactive STEM instructional media.

In summary, the structural model examined learner characteristics across nine projectile representation types (Table 2). Self-efficacy was a consistent predictor, negatively influencing preference for text (β = –.179, p < .001) and equations (β = –.160, p < .001), but positively influencing interactive simulations (β = .152, p < .001). Affective empathy negatively predicted equations (β = –.190, p < .001) but positively predicted pseudo-realistic + force images (β = .122, p < .001). Cognitive empathy positively predicted conceptually rich formats such as GIFs (β = .108, p = .007) and pseudo-realistic visuals (β = .125, p < .001). Behavioral engagement showed a negative effect for GIFs (β = –.144, p = .046).

Table 2. Projectile Summary of Significant Predictors for Preference Across Projectile Representation Types.

Predictor	Text Description	Equations	GIF	Line Illustration Image	Line Illustration + Force	Pseudo-realistic Image	Pseudo-realistic + Force	Abstract Free Body Image	Interactive Simulation
Affective Empathy (AEm)	NS	Sig (-)	NS	NS	NS	NS	Sig (+)	Sig (-)	Sig (+)
Behavioral Engagement (BE)	NS	NS	Sig (-)	NS	NS	NS	NS	Sig (-)	NS

Cognitive Empathy (CEm)	NS	NS	Sig (+)	NS	NS	Sig (+)	NS	NS	Sig (+)
Cognitive Engagement (CEn)	NS	NS	NS	NS	NS	Sig (+)	Sig (-)	NS	NS
Emotional Engagement (EE)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Self-Efficacy (SEF)	Sig (-)	Sig (-)	Sig (+)	NS	Sig (-)	NS	Sig (+)	NS	Sig (+)

Note. ns = not significant ($p \geq .05$); + = significant positive relationship ($p < .05$); – = significant negative relationship ($p < .05$)

Discussion. These findings illustrate the differential roles of learner traits in shaping visual representation preferences in projectile motion education. Notably, self-efficacy was the most consistently influential variable, significantly predicting preferences across five modalities, positively for more interactive or visual formats and negatively for text and equation-based content. This underscores the need to design differentiated instruction based on learners' confidence and autonomy.

Empathy dimensions, both affective and cognitive, also played a pivotal role. Learners with high affective empathy preferred immersive visuals (e.g., pseudo-realistic + force, interactive simulations) but avoided highly technical formats like equations and abstract diagrams. Cognitive empathy had a dual effect: it positively predicted preferences for conceptually rich formats (interactive simulations, pseudo-realistic images) and negatively predicted preferences for less detailed representations.

Interestingly, behavioral and emotional engagement were less predictive across formats, except in specific cases such as abstract representations (negative) or GIFs (negative for behaviorally engaged learners). These insights suggest that while affect and cognition strongly shape visual preferences, engagement types may interact with the instructional context rather than acting as consistent predictors.

In summary, the results support the value of personalizing visual instruction in physics education, especially in topics like projectile motion, where representation format significantly impacts comprehension. Tailoring visual modalities to align with learners' empathy, confidence, and engagement profiles can lead to more effective and inclusive STEM education.
These patterns suggest that confident learners prefer exploratory visuals, empathetic learners favor contextually rich images, and active learners prefer less passive content. The findings align with prior research linking empathy and engagement to visual learning preferences [22, 23].

Motion

Among the eight motion-based representations, pseudo-realistic images demonstrated the broadest influence of learner characteristics. Both affective empathy ($\beta = .138$, $p < .001$) and behavioral engagement ($\beta = .117$, $p = .046$) were positively associated with preference, while cognitive engagement showed a significant adverse effect ($\beta = -.099$, $p = .005$). This suggests that learners who are emotionally attuned and behaviorally active may prefer visually immersive and lifelike representations. In contrast, those who engage more deeply in mental elaboration might find pseudo-realism overly concrete or distracting.

For animated line illustrations, three variables were statistically significant. Cognitive empathy negatively predicted preference ($\beta = -.156$, $p < .001$), while cognitive engagement ($\beta = .082$, $p = .026$) and self-efficacy ($\beta = .110$, $p = .001$) positively predicted it. This result indicates that learners who are more confident and cognitively active may appreciate the clarity and structure of line animations. At the same time, those high in perspective-taking may gravitate toward more nuanced or abstract visuals.

In the 3D outline condition, cognitive empathy ($\beta = .147$, $p < .001$) emerged as a positive predictor, and cognitive engagement ($\beta = -.121$, $p = .001$) was negatively associated with preference. This dual pattern implies that learners with strong empathetic reasoning may benefit from 3D structural aids. At the same time, those who are cognitively reflective may prefer formats that emphasize conceptual rather than spatial content.

For colored 3D illustrations, cognitive empathy ($\beta = -.064$, $p = .040$) and self-efficacy ($\beta = -.134$, $p < .001$) were significant negative predictors, suggesting that increased color or visual embellishment may reduce appeal among learners who are confident or cognitively empathetic, possibly due to perceived visual overload or distraction.

Preference for animated equations was significantly predicted only by cognitive empathy ($\beta = .097$, $p = .005$), reinforcing that abstract, symbolic formats appeal more to learners who can understand others' reasoning and internal states, which indicate skills that are aligned with advanced cognitive functions.

Other motion-based formats, such as 3D illustrations, colored 3D visuals, and colored line visuals, yielded no significant predictors (all $ps > .05$). This implies that learner preferences for these formats may be less dependent on individual psychological traits and more influenced by design or instructional context.

In summary, the motion curriculum (Table 3), pseudo-realistic images elicited the strongest responses. Affective empathy ($\beta = .138$, $p < .001$) and behavioral engagement ($\beta = .117$, $p = .046$) were positive predictors, while cognitive engagement negatively predicted preference ($\beta = -.099$, $p = .005$). For line illustrations, cognitive engagement ($\beta = .082$, $p = .026$) and self-efficacy ($\beta = .110$, $p = .001$) were positive predictors. Cognitive empathy positively predicted animated equations ($\beta = .097$, $p = .005$).

These results demonstrate that learners high in empathy and engagement prefer distinct modalities. Emotionally engaged learners are drawn to immersive visuals, while cognitively reflective students prefer structured illustrations and symbolic logic.

Table 3. Motion Summary of Significant Predictors for Preference Across Motion Curriculum Preferences

Predictor	Equations	3D Outline	3D Illus	Colored 3D Illus	Colored Red 3D Illus	Colored Line Illus	Line Illus	Pseudo-realistic
Affective Empathy (AEm)	NS	NS	NS	NS	NS	NS	NS	Sig (+)
Behavioral Engagement (BE)	NS	NS	NS	NS	NS	NS	NS	Sig (+)
Cognitive Empathy (CEm)	Sig (+)	Sig (+)	NS	Sig (-)	NS	NS	Sig (-)	NS
Cognitive Engagement (CEn)	NS	Sig (-)	NS	NS	NS	NS	Sig (+)	Sig (-)
Emotional Engagement (EE)	NS	NS	NS	NS	NS	NS	NS	NS
Self-Efficacy (SEF)	NS	NS	NS	Sig (-)	NS	NS	Sig (+)	NS

Note. ns = not significant ($p \geq .05$); + = significant positive relationship ($p < .05$); – = significant negative relationship ($p < .05$)

Discussion. The findings from the motion curriculum reinforce earlier patterns observed in the static and projectile conditions, particularly the centrality of cognitive empathy, cognitive engagement, and self-efficacy in determining visual preferences.

Cognitive empathy consistently emerged as a key predictor but varied in direction: it positively influenced preference for animated equations and 3D outlines but negatively affected preference for line illustrations and colored 3D visuals. This suggests that learners with greater ability to understand others' perspectives are more selective in their visual preferences, favoring structured or conceptually dense representations over visually enhanced or expressive ones.

Cognitive engagement also showed bidirectional effects, positively predicting a preference for line illustrations (where clarity is key) and negatively predicting a preference for pseudo-realistic and 3D outlines (which may lack perceived depth or challenge). This implies that cognitively reflective learners prioritize formats that support logical integration and mental effort.

Self-efficacy positively predicted preference for line illustrations but negatively for colored 3D visuals. This may indicate that confident learners seek visual clarity and minimalism, avoiding designs that feel overly stylized or didactic.

The consistent significance of these variables across formats suggests that motion-based learning design should be adaptive to learner profiles. While highly visual and pseudo-realistic formats may enhance engagement for empathetic and behaviorally active learners, they may not align with the preferences of self-directed or cognitively driven individuals.

In summary, the motion curriculum findings highlight the need for instructional personalization in engineering and physics education. Matching visual complexity, style, and animation to learner characteristics can optimize both preference and likely comprehension outcomes. These findings are further supported by researchers [7, 8], who emphasize that emotional engagement and belonging are central to how learners interact with visual representations in technical fields, particularly for students from underrepresented groups.

These insights can inform user-centered design approaches in STEM instructional media, particularly when developing intelligent tutoring systems or adaptive learning platforms.

Magnetic

Across the seven visual representations analyzed, several predictors emerged as statistically significant ($p < .05$), indicating that learner traits meaningfully shaped preferences for magnetic field representations.

In the equation format, both cognitive empathy ($\beta = .044$, $p = .005$) and cognitive engagement ($\beta = .105$, $p = .005$) were positively associated with preference. This suggests that learners who are more capable of understanding others' perspectives and engaging in reflective, mental elaboration are more likely to prefer abstract, symbolic representations of magnetic concepts.

For line illustrations, affective empathy had a negative relationship with preference ($\beta = -.074$, $p = .025$), while cognitive empathy ($\beta = .148$, $p < .001$) and cognitive engagement ($\beta = .197$, $p < .001$) were positively related. This pattern suggests that learners with stronger affective sensitivity may find line illustrations too impersonal or abstract, whereas cognitively oriented learners prefer their conceptual simplicity.

In the colored line illustration condition, multiple variables were significant: cognitive empathy ($\beta = -.105$, $p = .001$) had a negative association, while cognitive engagement ($\beta = .106$, $p = .005$), emotional engagement ($\beta = .099$, $p = .009$), and self-efficacy ($\beta = -.103$, $p = .003$) were positively associated. These results reveal a nuanced pattern: while colored enhancements may appeal to emotionally engaged and cognitively active learners, those with high perspective-taking abilities may view such formats as overly stylized or lacking conceptual depth.

Among the 3D illustration types, the basic 3D illustration format showed strong positive effects from cognitive empathy ($\beta = .268$, $p < .001$), but negative effects from cognitive engagement ($\beta = -.159$, $p < .001$), emotional engagement ($\beta = -.113$, $p = .002$), and self-efficacy ($\beta = -.126$, $p < .001$). These results suggest that while learners with perspective-taking ability favor spatially rich formats, more confident and emotionally engaged learners may perceive them as unnecessarily complicated.

The colored 3D illustration format presented a similar pattern: affective empathy ($\beta = -.278$, $p < .001$), cognitive empathy ($\beta = -.134$, $p < .001$), and self-efficacy ($\beta = -.130$, $p < .001$) were all negatively associated with preference, while emotional engagement ($\beta = .086$, $p = .028$) had a positive effect. These findings suggest that despite their aesthetic appeal, colored 3D visuals may be perceived as excessive or less pedagogically applicable by confident and cognitively attuned learners.

In the 3D illustrations with force vectors, only self-efficacy ($\beta = -.073$, $p = .027$) significantly influenced preference, showing a negative relationship. This trend continued in the colored 3D + force condition, where again only self-efficacy ($\beta = .164$, $p < .001$) was a significant positive predictor. These results indicate that force vector enhancements might appeal more to learners who are highly confident in their ability to interpret and apply complex visuals.

In summary, the magnetic domain revealed distinct patterns (Table 4). Cognitive empathy and cognitive engagement positively predicted preference for equations and line visuals but negatively for colored 3D formats ($\beta = -.134$, $p < .001$). Emotional engagement positively predicted preference for colored visuals ($\beta = .099$, $p = .009$). Self-efficacy negatively predicted preference for 3D and colored visuals ($\beta = -.126$, $p < .001$) but positively predicted preference when force vectors were included ($\beta = .164$, $p < .001$).

These findings suggest that cognitive and emotional variables influence visual tolerance for complexity. Learners with high empathy value precision, while confident learners prefer representations that challenge rather than simplify concepts.

Table 4. Magnetic Summary of Significant Predictors for Preference Across Magnetic Curriculum Preferences.

Predictor	**Equations**	**Line Illustration**	**Colored Line Illus**	**3D Illus**	**Colored 3D Illus**	**3D Illus + Force**	**Colored 3D Illus + Force**
Affective Empathy (AEm)	NS	Sig (-)	NS	NS	Sig (-)	NS	NS
Behavioral Engagement (BE)	NS	NS	NS	NS	NS	NS	NS
Cognitive Empathy (CEm)	Sig (+)	Sig (+)	Sig (-)	Sig (+)	Sig (-)	NS	NS
Cognitive Engagement (CEn)	Sig (+)	Sig (+)	Sig (+)	Sig (-)	NS	NS	NS
Emotional Engagement (EE)	NS	NS	Sig (+)	Sig (-)	Sig (+)	NS	NS
Self-Efficacy (SEF)	NS	NS	Sig (+)	Sig (-)	Sig (-)	Sig (+)	Sig (+)

Note. ns = not significant ($p \geq .05$); + = significant positive relationship ($p < .05$); – = significant negative relationship ($p < .05$)

Discussion. The results for the magnetic curriculum reinforce earlier findings from the static, projectile, and motion curricula, particularly the dominant roles of cognitive empathy, cognitive engagement, and self-efficacy in shaping preferences. However, the magnetic domain also reveals a distinctive pattern: preferences appear to diverge sharply depending on whether the representation is abstract (e.g., equations, line diagrams) or visually enriched (e.g., 3D illustrations, force vector overlays).

Cognitive empathy was a key predictor across both ends of the visual spectrum. While it positively predicted preference for equations and line visuals, it negatively predicted preference for colored visuals and 3D representations. This suggests that learners with advanced perspective-taking skills value conceptual precision over sensory engagement.

Cognitive engagement showed a consistently positive association with preference for diagrams and structured visuals, and a negative association with 3D or colored visuals, aligning with the view that such learners prefer formats that support logical structuring over perceptual embellishment.

Self-efficacy was particularly interesting: it negatively predicted preference for several formats of basic 3D, colored 3D, and force-overlaid visuals, yet positively predicted preference for colored 3D + force visuals. This contradiction may reflect a nonlinear relationship, where confident learners may reject visual styles that appear redundant or condescending, but value those that effectively support expert-level interpretation (e.g., when vector information is added to spatial models).

Finally, emotional engagement only emerged in select conditions. It was positively associated with colored visuals, suggesting its relevance when color or motion is used to simulate emotional salience or guide attention.

In summary, the magnetic curriculum findings emphasize the importance of tailoring visual complexity to the learner's cognitive and emotional profile. Formats that balance visual appeal with conceptual clarity, such as line diagrams with minimal enhancements or 3D visuals with functionally informative overlays, may offer the best compromise across diverse learner types.

Pythagorean Theorem

We chose the Pythagorean representations because the theorem is fundamental to math. Most students, prior to entering any college, should have been exposed to the Pythagorean theorem. In this section, we provide details regarding the representations of the Pythagorean theorem. All students received the representations as a word problem, equation, line drawings, and pseudo-realistic forms.

Word Problem: Pythagorean Theorem

The Pythagorean Theorem allows us to determine the length of one side of a right triangle if we know the length of the other two sides. A right triangle has a 90-degree angle and three sides. The two shorter sides are called legs, and the longer side is the hypotenuse. The relationship between the lengths of the three sides is that the length of the hypotenuse is equal to the square root of the sum of the squares of the lengths of each of the legs. By doing algebraic manipulation, you can determine the length of any side if you know the lengths of the other two sides. By using the Pythagorean Theorem, you can determine how far the base of a ladder is from a wall if you know the length of the ladder and how high the ladder touches the wall.

$$a^2 + b^2 = c^2$$

Figure 1. Pythagorean Theorem Equation

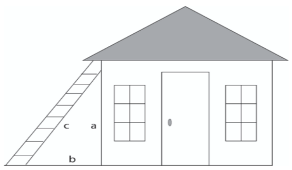

Figure 2. A pseudo-realistic representation of the problem in a real-world application, with the sides of the right triangle labeled

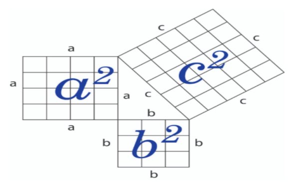

Figure 3. A drawing showing the relationship of the triangle sides to squares that shows the area of the squares and shows their relationship to the Pythagorean Theorem

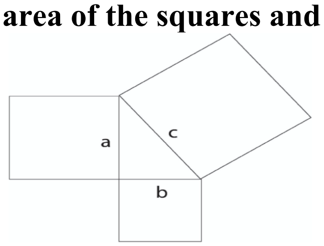

Figure 4. A drawing showing the relationship of the triangle to the squares

This section summarizes the structural model results examining how six learner characteristics: affective empathy, behavioral engagement, cognitive empathy, cognitive engagement, emotional engagement, and self-efficacy predict students' preferences for different representations of the Pythagorean Theorem (see Table 5). Eight types of representations were assessed, ranging from text and mathematical expressions to various forms of triangle-square visuals and pseudo-realistic images (not all are presented in this section, 5 out of 8).

Affective empathy (AEm) emerged as the most consistent positive predictor across formats. It significantly predicted preferences for text description ($\beta = .143$, $p < .001$), mathematical explanation ($\beta = .122$, $p = .001$), triangle-square area visualizations ($\beta = .130$, $p < .001$), and pseudo-real-world labeled images ($\beta = .098$, $p = .003$). These findings suggest that students who are emotionally attuned and value personal resonance with instructional material are more drawn to verbal, narrative, and visually guided content. Interestingly, AEm also negatively predicted preference for more structured visual representations such as triangle-square drawing ($\beta = –.096$, $p = .036$) and triangle-square Pythagorean diagrams ($\beta = –.087$, $p = .013$), indicating a possible discomfort with diagrammatic abstraction.

Cognitive empathy (CEm) showed a strong influence in selective areas. It positively predicted preference for abstract triangle diagrams ($\beta = .099$, $p = .005$) and triangle-square drawing

(β =.124, p = .001), suggesting that students who are capable of perspective-taking and reasoning about others' thinking may be drawn to conceptual, schematic visuals. However, CEm negatively predicted preference for pseudo-real labeled (β = –.152, p < .001) and pseudo-real app-based representations (β = –.149, p < .001), indicating that such learners may view real-world or app-enhanced visuals as lacking in conceptual depth or overly constrained by context.

Behavioral engagement (BEn) showed limited predictive power overall, but it marginally predicted a negative preference for pseudo-real labeled visuals (β = –.075, p = .057). This suggests that highly behaviorally active students may find these representations insufficiently interactive or too passively observational.

Cognitive engagement (CEn) significantly negatively predicted preference for pseudo-real app-based representations (β = –.119, p = .002), further reinforcing the idea that students who are more mentally invested in learning may not find app-based interfaces sufficiently challenging or conceptually rich.

Emotional engagement (EEn) was positively associated only with pseudo-real labeled visuals (β = .160, p = .014) but negatively predicted preference for pseudo-real app-based representations (β = –.083, p = .050). These opposing patterns may reflect the importance of clarity and emotional salience in static images, as well as possible confusion or cognitive overload in app-based content.

Self-efficacy (SEF) significantly negatively predicted preferences for triangle-square area (β = –.076, p = .027) and triangle-square Pythagorean visuals (β = –.085, p = .016). These results suggest that students with higher confidence in their problem-solving abilities may prefer more abstract, less scaffolded representations and may find overt visual aids redundant.

In summary, the Pythagorean condition (Table 5) revealed that affective empathy positively predicted preference for text descriptions (β = .143, p < .001), math explanations (β = .122, p = .001), and pseudo-real labeled images (β = .098, p = .003). Cognitive empathy predicted preference for abstract and schematic visuals but negatively predicted pseudo-realistic formats (β = –.152, p < .001). Cognitive and emotional engagement negatively predicted preference for pseudo-real app-based representations. Self-efficacy negatively predicted preference for scaffolded visuals such as area diagrams (β = –.085, p = .016).

These findings suggest that affectively empathetic students gravitate toward narrative and relational learning, while cognitively reflective and confident learners prefer abstraction and minimalism.

Table 5. Pythagorean Theorem Summary of Significant Predictors for Preference Across Pythagorean Theorem Curriculum Preferences

Predictor	Text Description	Math Explanation	Abstract Triangle	Triangle-Square Drawing	Triangle-Square Area	Triangle-Square Pythagoras	Pseudo-Real Label	Pseudo-Real App
Affective Empathy (AEm)	Sig (+)	Sig (+)	NS	Sig (-)	Sig (+)	Sig (-)	Sig (+)	NS
Behavioral Engagement (BEn)	NS	NS	NS	NS	NS	NS	Sig (-)	NS
Cognitive Empathy (CEm)	NS	NS	Sig (+)	Sig (+)	NS	NS	Sig (-)	Sig (-)
Cognitive Engagement (CEn)	NS	NS	NS	NS	NS	NS	NS	Sig (-)
Emotional Engagement (EEn)	NS	NS	NS	NS	NS	NS	Sig (+)	Sig (-)
Self-Efficacy (SEF)	NS	NS	NS	NS	Sig (-)	Sig (-)	NS	NS

Note. ns = not significant ($p \geq .05$); + = significant positive relationship ($p < .05$); – = significant negative relationship ($p < .05$)

Discussion. The findings from the Pythagorean Theorem Curriculum condition offer valuable insights into how psychological characteristics shape preferences for mathematical representations. Affective empathy was the most robust and consistent predictor, particularly favoring more verbal and narrative-rich formats. Students with high AEm may seek representations that foster emotional connection, clarity, and narrative structure.

In contrast, cognitive empathy showed a clear preference for conceptual and abstract visualizations (e.g., triangle drawings) while avoiding overly contextualized, real-world formats. This suggests that such learners are more comfortable with representations that require mental reconstruction and abstract reasoning.

Engagement dimensions, particularly cognitive and emotional, were most relevant in shaping responses to pseudo-realistic and app-based content. Learners who are mentally and emotionally invested in learning tend to view highly contextual or digitally mediated representations as less valuable, potentially due to perceived distraction, lack of depth, or cognitive overload. Self-efficacy also played a key role in reducing preference for scaffolded visuals, such as area-based or highly illustrative triangle-square formats. Confident learners may not feel the need for concrete visual support and prefer more symbolic or abstract representations aligned with their skills. This is consistent with prior research linking higher self-efficacy to preferences for minimalist, less-scaffolded instructional formats [24] suggesting that confident learners may perceive detailed visual supports as redundant rather than helpful.

Together, these results highlight that preferences for mathematical representations are not uniform but are meaningfully shaped by empathy, engagement style, and learner confidence. These findings reinforce the need for differentiated instructional design in mathematics education, particularly in early geometry and algebra contexts, where offering multiple types of representations can help meet students where they are emotionally, cognitively, and motivationally.

Integrated Interpretation and Educational Implications

From an equity and social justice perspective, the present findings also illuminate how representation choices in engineering curricula can function as mechanisms of inclusion or exclusion within classroom practice. When instructional formats privilege highly abstract or decontextualized representations, they may inadvertently align with dominant norms of engineering cognition while marginalizing learners whose engagement is relational, contextual, or affectively grounded. This is not merely a matter of individual learning style but reflects broader structural inequities in whose knowledge practices are legitimized within engineering education, making psychologically responsive curriculum design an act of resistance as much as an act of pedagogy. Conversely, multimodal and empathy-responsive design expands the epistemic space of the classroom by legitimizing diverse ways of interacting with technical knowledge. In this way, the engineering classroom becomes a site where liberatory pedagogy is not merely aspirational but practically enacted through deliberate representational choices. In this sense, psychologically responsive curriculum design represents a practical pathway for enacting culturally sustaining and liberatory pedagogy in engineering education.

These findings carry concrete implications across three interconnected domains. For research, this study demonstrates the value of integrating psychological constructs into quantitative models of curriculum preference, opening pathways for longitudinal investigation of how empathy and self-efficacy interact with identity factors such as race, gender, and first-generation status. Future studies should also examine whether the predictive patterns identified here hold across different institutional types, cultural contexts, and disciplines. For educational practice, instructors can use empathy and engagement informed frameworks to design differentiated learning experiences. For instance, pairing abstract representations with relational or narrative supports to meet the needs of affectively engaged learners alongside their cognitively driven peers. Professional development programs could help faculty recognize and respond to psychological diversity in their classrooms rather than defaulting to uniform instructional formats. For educational technology and design, developers of intelligent tutoring systems and adaptive learning platforms can embed psychological profiling into content delivery to match representation type with learner profile, while attending carefully to equity implications of algorithmic personalization.

Across all curricula, empathy, engagement, and self-efficacy interact dynamically to shape learning preferences. Affective empathy enhances attraction to expressive, emotionally salient materials, while cognitive empathy aligns with structured, conceptually rich formats. Behavioral and emotional engagement influence interactivity preferences, and self-efficacy moderates tolerance for complexity. These findings support learner-centered design principles, reinforcing the value of multimodal and adaptive instruction [22].

Implementing psychologically responsive design in engineering education can address both cognitive and affective dimensions of learning. This approach supports equity and inclusion by valuing diverse epistemologies and modes of engagement, echoing calls from recent ASEE initiatives to humanize engineering pedagogy [24, 25].

Conclusion

The findings from this study underscore the complex and multidimensional nature of learning preferences in engineering education. Empathy, engagement, and self-efficacy jointly influence how students process, value, and interact with various representations of technical content. Affective empathy enhances receptivity to narrative and emotionally salient materials, while cognitive empathy correlates with conceptual abstraction and structured logic. Cognitive and behavioral engagement highlight learners' active participation in meaning-making, while self-efficacy serves as a moderating variable, determining whether students gravitate toward exploratory or minimalist visual designs.

This expanded understanding of psychological and engagement factors reinforces the need for human-centered approaches in engineering pedagogy [9]. Integrating adaptive, multimodal instructional materials that address affective as well as cognitive dimensions can foster deeper learning, motivation, and persistence. For underrepresented students, especially those who have historically encountered barriers to belonging, empathetic and inclusive curriculum design offers an avenue to enhance equity and participation. By recognizing that different learners interpret complexity, abstraction, and emotion through unique psychological lenses, educators can design courses that honor diverse epistemologies and learning pathways.

From a broader perspective, the study contributes to ongoing efforts to reform engineering education through evidence-based and inclusive frameworks. These results have practical implications for faculty development, educational technology design, and curriculum assessment. Educators can use empathy and engagement-informed data to refine learning experiences. In contrast, developers of intelligent tutoring systems and AI-driven adaptive learning platforms can embed psychological profiling to personalize content delivery.

Ultimately, fostering inclusive excellence in engineering education requires understanding students as more than cognitive agents but rather as affective and social beings. A comprehensive, psychologically grounded approach can cultivate both technical proficiency and humanistic awareness, producing engineers who are not only competent but also empathetic, reflective, and ethically attuned to the challenges of an increasingly representational and interconnected world.

From an educational perspective, these results suggest that instructional design for physics and engineering courses should integrate a balance of visual modalities that cater to diverse learner profiles. Highly confident students may benefit from exploratory simulations that encourage autonomy and experimentation, while emotionally responsive learners may thrive with visuals that connect abstract principles to relatable contexts. These findings support the use of multimodal instructional strategies that balance analytical precision and emotional engagement, promoting inclusion and persistence among diverse learner populations.

Viewing the engineering classroom as a terrain of struggle and site of possibility, this study demonstrates that representation design is not merely a pedagogical preference but an equity practice shaping whose learning preferences are recognized and supported.

Future Work

Future research should expand on longitudinal studies that examine how these psychological dimensions evolve across academic stages and intersect with identity factors such as race, gender, and first-generation status.
Future research should explore longitudinal studies that track changes in empathy, engagement, and self-efficacy over time, particularly as students progress through different phases of their engineering education [26]. Examining how these psychological variables evolve can reveal whether instructional interventions or curricular redesigns have lasting effects on learning preferences and retention. Moreover, future work should include cross-institutional and cross-cultural comparisons to determine whether these findings generalize beyond U.S. contexts or vary across educational systems and cultural values.

Another promising direction is the integration of artificial intelligence and learning analytics to create adaptive, data-informed systems that dynamically match instructional representations with learner profiles. Investigating how AI-driven personalization influences equity and inclusion will be vital for understanding both opportunities and risks in emerging educational technologies [24]. Qualitative research, such as interviews and focus groups, can complement quantitative modeling by uncovering the lived experiences and narratives that underlie learners' visual and emotional preferences.

Finally, interdisciplinary collaborations between engineers, psychologists, and educators can deepen the understanding of empathy and engagement as key factors in STEM learning [12, 27]. Future ASEE studies can extend this work into practical applications, developing professional development programs that help instructors recognize and respond to psychological diversity in their classrooms.

Centering the voices and experiences of historically marginalized students in this future work will be essential to ensuring that psychologically responsive design serves genuine equity goals rather than simply optimizing engagement within existing structural arrangements.

References

[1] Y.S. George, D.S. Neale, V. Van Horne, and S. M. Malcom. In pursuit of a diverse science, technology, engineering, and mathematics workforce: Recommended research priorities to enhance participation by underrepresented minorities. In *American Association for the Advancement of Science*, pp. 1-32, December 2001.

[2] S. M. Malcom, P. Q. Hall, and J. W. Brown. The double bind: The price of being a minority woman in science. In *American Association for the Advancement of Science*. 1976.

[3] M. Ong, C. Wright, L. Espinosa, and G. Orfield. Inside the double bind: A synthesis of empirical research on undergraduate and graduate women of color in science, technology, engineering, and mathematics. *Harvard Educational Review,* vol.8, no.2, 172–209, 2011. https://doi.org/10.17763/haer.81.2.t022245n7x4752v2

[4] National Science Foundation. *The state of U.S. science and engineering.* 2022. https://ncses.nsf.gov/pubs/nsb20221

[5] J. Holly Jr. Criticality is crucial: Fidelity in what we say and do. *Studies in Engineering Education,* vol. 2, no. 2. 2021.

[6] E. O. McGee and W. H. Robinson. *Diversifying STEM: Multidisciplinary perspectives on race and gender.* Rutgers University Press. 2020.

[7] J. Lönngren, A. Bellocchi, M. Berge, P. Bøgelund, I. Direito, J. L. Huff, K. Mohd-Yusof, H. Murzi, N. Farahwahidah Abdul Rahman, and R. Tormey. Emotions in engineering education: A configurative meta-synthesis systematic review. *Journal of Engineering Education*, vol. 113, no. 4, 1287–1326, 2024. https://doi.org/10.1002/jee.20600

[8] A. Anwar, I. U. Rehman, M. M. Nasralla, S. B. A. Khattak, and N. Khilji. Emotions matter: A systematic review and meta-analysis of the detection and classification of students' emotions in stem during online learning. *Education Sciences*, vol. 13, no. 9, 914, 2023.

[9] S. Tettegah, J. Young, E. Larnyo, C. Terry, D. Vallett, Y. Jiang, and A. Craig. An examination of user preferences and creativity in engineering Education. *Schools Journal.* University of Chicago Press. 2024. https://doi.org/10.1086/732437

[10] M. Daun, J. Brings, V. Trzpiot, and P. A. Obe. Learner preferences in software engineering education: A comparative study of similarities and differences between university students and industry professionals. *2025 IEEE/ACM 37th International Conference on Software Engineering Education and Training (CSEE&T)*, Ottawa, ON, Canada, 87–97, 2025. doi: 10.1109/CSEET66350.2025.00016.

[11] C. Camacho-Zúñiga, S. Salas-Maxemín, A. P. Valle-Arce, P. Caratozzolo, and G. M. Chans. Toward a continuous learning educational model: insights from the experience of a Mexican private university. *Front. Educ*. 10:1485034, 2025. doi: 10.3389/feduc.2025.1485034

[12] S. Lavado-Anguera, P-J. Velasco-Quintana, and M.-J. Terrón-López. Project-based learning (PBL) as an experiential pedagogical methodology in engineering education: A review of the literature. *Education Sciences*, vol. *14*, no. 6, 617, 2024. https://doi.org/10.3390/educsci14060617

[13] A. Bandura. *Self-efficacy: The exercise of control.* W. H. Freeman and Company. 1997.

[14] Y-P. Hsu, D. F. Chiang, and I. Kehinde. Transforming engineering education in the digital era: findings from a systematic review. *Front. Educ*. 10:1568917. 2025. doi: 10.3389/feduc.2025.1568917

[15] S. Tettegah. Rethinking engineering education why focusing on learning preferences matters for diversity. *The Conversation,* 21, May 2025. https://theconversation.com/rethinking-engineering-education-why-focusing-on-learning-preferences-matters-for-diversity-251095

[16] C. C. Wu and T. H. Wang. What is the role of learning style preferences on the STEM learning attitudes among high school students? *International Journal of Educational Research*, *vol. 129*, 102488, 2025. https://doi.org/10.1016/j.ijer.2024.102488

[17] M. H. Davis. Measuring individual differences in empathy: Evidence for a multidimensional approach. *Journal of Personality and Social Psychology*, vol. 44, no. 1, 113–126, 1983. https://doi.org/10.1037/0022-3514.44.1.113

[18] D. Jolliffe and D. P. Farrington. Development and validation of the Basic Empathy Scale. *Journal of Adolescence,* vol. 29, no. 4, 589–611, 2006. https://doi.org/10.1016/j.adolescence.2005.08.010

[19] J. Reeve and C. M. Tseng. Agency as a fourth aspect of students' engagement during learning activities. *Contemporary Educational Psychology*, vol. 36, no. 4, 257-267, 2011.

[20] C. Midgley, M. L. Maehr, L. Z. Hruda, E. Anderman, L. Anderman, K. E. Freeman, and T. Urdan. Manual for the patterns of adaptive learning scales. *Ann Arbor: University of Michigan*, 734-763, 2000.

[21] E. M. Skaalvik, R. A. Federici, and R. M. Klassen. Mathematics achievement and self-efficacy: Relations with motivation for mathematics. *International Journal of Educational Research*, *72*, 129-136, 2015.

[22] M. A. Alzayed, C. McComb, J. Menold, J. Huff, and S. R. Miller. Are you feeling me? An exploration of empathy development in engineering design education. *Journal of Mechanical Design*, vol. 143, no. 11, 112301, 2021.

[23] H. L. Morano, and M. L. Cole. "Promoting empathy in engineering undergraduates: An assessment of the efficacy of an interdisciplinary service-learning design course", 2024 ASEE Annual Conference & Exposition, Portland, Oregon, 10.18260/1-2—47892, June 2024.

[24] G. D. Furman. "Enhancing engineering education: The role of artificial intelligence in personalizing learning and outcomes," *2024 4th International Conference on Big Data Engineering and Education (BDEE)*, Chiangmai, Thailand, pp. 61-65, 2024. doi: 10.1109/BDEE63226.2024.00018.

[25] S. H. Jones, B. D. Campbell, and I. Villanueva. An investigation of self-efficacy and topic emotions in entry-level engineering design learning activities. *The International journal of engineering education*, vol. 35, no. 1, 15-25, 2019.

[26] T. Litzinger, L. R. Lattuca, R. Hadgraft, and W. Newstetter. Engineering education and the development of expertise. *Journal of Engineering Education*, vol. *100*, no. 1, 123–150. 2011. https://doi.org/10.1002/j.2168-9830.2011.tb00006.x