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Psychosocial and Technological Predictors of Online Learning Engagement in Mechanical Engineering Education

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ABSTRACT:

This study addresses the persistent challenge of sustaining deep and meaningful engagement in online mechanical engineering education, an inherently hands-on discipline where traditional laboratory-based learning is difficult to replicate in virtual settings. Despite the rapid advancement of educational technology, many online learning environments in engineering continue to be characterized by reduced interaction, weakened social presence, and declining student motivation. To address this issue, the present study examines the psychosocial and technological factors influencing online learning engagement among mechanical engineering undergraduates in China, drawing on Self-Determination Theory (SDT) and Social Cognitive Theory (SCT). A quantitative survey design was employed, involving 212 students from Guangzhou Vocational College of Technology & Business. Validated instruments were used to measure online self-efficacy, teacher emotional support, social presence, and online student engagement. Statistical analyses, including reliability tests, factor validation, and correlation analysis, revealed that social presence ($r = 0.571$, $p < 0.01$) and self-efficacy ($r = 0.246$, $p < 0.01$) were strong positive predictors of engagement, whereas teacher emotional support ($r = 0.134$, $p < 0.05$) showed a weaker but significant effect. These results suggest that in technically demanding fields such as mechanical engineering, students' engagement is more powerfully driven by their perceived competence and sense of social connectedness than by emotional encouragement alone. The integration of SDT and SCT in this study provides a comprehensive, interdisciplinary model that explains how motivational belief systems (self-efficacy) and environmental factors (teacher support and social presence) interact to sustain online engagement. The findings offer theoretical contributions to the psychology of digital learning and practical guidance for educators seeking to design human-centered, socially interactive, and competence-oriented online environments for technical and engineering disciplines.

KEYWORDS:
Online learning engagement, self-efficacy, teacher emotional support, social presence, mechanical engineering education, Self-Determination Theory, Social Cognitive Theory

1. Introduction

Mechanical engineering, as a discipline deeply rooted in the integration of theoretical knowledge and practical application, imposes high cognitive and technical demands on students' mastery of both conceptual content and hands-on skills. In recent years, online learning has emerged as a flexible and diverse educational model, reshaping how mechanical engineering students acquire knowledge and competencies [1]. Traditionally, mechanical engineering education has emphasized laboratory experiments, experiential training, and face-to-face interaction between instructors and students. However, the transition toward online and technology-mediated formats has raised legitimate concerns about whether such modes can replicate the depth of engagement that traditional teaching fosters.

Student engagement, conceptualized as behavioral, emotional, and cognitive participation in learning activities, has long been recognized as a critical determinant of academic success and persistence [2]. Yet, the online learning environment presents persistent challenges, including high dropout rates, superficial learning, and weakened interpersonal interaction [3]. These issues underscore the urgent need to identify mechanisms that sustain online engagement, particularly in disciplines characterized by high practical and technical requirements such as mechanical engineering.

Despite rapid technological advancements in online learning systems, the primary challenge facing educators and researchers in mechanical engineering is sustaining deep and continuous engagement in virtual learning environments that lack tangible, laboratory-based experiences. Unlike humanities or social science courses that rely on discussion and reflection, mechanical engineering education depends on practical experimentation, simulation, and applied reasoning, all of which are difficult to replicate online. Consequently, many students experience disengagement, reduced motivation, and a disconnection between theoretical instruction and real-world application. This challenge is further exacerbated by limited instructor interaction and insufficient social presence, which weaken the affective and collaborative dimensions essential for maintaining learner interest and persistence [4].

Therefore, this study addresses the core research problem of understanding how psychosocial and technological factors jointly influence online learning engagement among mechanical engineering students. By integrating Self-Determination Theory (SDT) and Social Cognitive Theory (SCT), this research constructs and empirically validates an interdisciplinary model that captures both motivational (internal) and environmental (external) influences on engagement [5,6]. Solving this problem is critical not only for improving instructional design and learner motivation but also for developing a sustainable and human-centered approach to online engineering education that aligns with global trends in digital pedagogy and applied learning.

Recent research has examined multiple layers of influence on online learning engagement, exploring how personal, instructional, and technological factors shape students' commitment [7]. However, most existing studies treat these factors in isolation, focusing predominantly on student-related or teacher-centered variables while overlooking synergistic effects between psychosocial and technological determinants such as self-efficacy, social presence, and teacher emotional support. Moreover, the majority of engagement studies have been concentrated within social science and humanities disciplines, resulting in limited empirical evidence concerning the online engagement of mechanical engineering students [8]. To bridge this gap, the present study integrates curriculum, social, and psychological dimensions to construct a holistic understanding of online engagement mechanisms within engineering education.

1.1 Context of Online Mechanical Engineering Education in China

In China, online mechanical engineering education has evolved into a multifaceted ecosystem characterized by both technological acceleration and domain-specific challenges [9]. Predominant delivery modes include synchronous and asynchronous teaching, blended learning, Massive Open Online Courses (MOOCs), virtual laboratories, and Learning Management Systems (LMS) [10]. Real-time online classes replicate traditional settings with high interaction [11], while self-paced formats offer flexibility but demand greater self-discipline [12]. Blended learning effectively merges digital content with offline practice, aligning closely with the practical nature of engineering tasks [13]. Despite their accessibility, MOOCs often suffer from low completion rates and limited interpersonal interaction [14]. Virtual labs and simulations provide partial substitutes for physical experiments [15], whereas LMS platforms remain the backbone of course management, assessment, and resource distribution.

This study focuses on real-time online learning (Live Online) to investigate the psychosocial and technological factors that influence student engagement [16]. The key challenge in this context lies in the weakened practical component, which constrains students' ability to apply knowledge and maintain motivation [8]. The core tension stems from the conflict between the discipline's hands-on requirements and the virtual limitations of online learning environments [4].

Within such settings, online self-efficacy becomes pivotal for learners' confidence in their ability to manage tasks and technologies, influencing persistence, attitudes, and performance [17]. Empirical evidence demonstrates a strong positive relationship between self-efficacy and cognitive engagement [18]. Likewise, social media literacy, or the effective and responsible use of communication technologies, facilitates engagement through collaboration and peer interaction [19].

1.2 Psychosocial and Technological Determinants of Engagement

Teacher emotional support plays a vital role in nurturing learners' intrinsic motivation and promoting deep engagement [20]. Grounded in Self-Determination Theory (SDT), emotionally supportive instruction satisfies students' psychological needs for autonomy, competence, and relatedness, enhancing both cognitive and affective participation [21,22]. Interactive course elements, such as teacher–student dialogue, peer collaboration, and responsive digital interfaces, further contribute to the development of social presence, a key construct influencing engagement [23,24]. Meanwhile, robust technological infrastructure and stable learning platforms ensure usability and satisfaction, forming the external foundation of sustained engagement [7].

1.3 Theoretical Framework

According to Self-Determination Theory [6], learners' self-directed behaviors are driven by the fulfillment of three core psychological needs: autonomy, competence, and relatedness [25]. Autonomy refers to the ability to make choices in learning activities; competence reflects one's belief in personal capability closely linked to self-efficacy; and relatedness denotes emotional support and connectedness, typically embodied in teacher–student interactions. Flexible learning tasks and constructive feedback enhance autonomy and competence [26], while emotionally supportive instruction fosters relatedness and intrinsic motivation [27]. Meeting these needs fosters sustained engagement, as learners perceive greater control, confidence, and a deeper connection in their online experience.

Social Cognitive Theory [6,28] emphasizes triadic reciprocal determinism, where personal factors (e.g., beliefs and self-efficacy), environmental factors (e.g., instructional design and peer interactions), and behavioral factors (e.g., engagement and participation) interact in a dynamic manner. In this framework, self-efficacy is a key personal determinant of effort, persistence, and task performance [29]. Environmental variables such as teacher support and social interaction serve as external reinforcements that can enhance self-efficacy by reducing anxiety and promoting motivation. Social presence, as an environmental factor, reflects the sense of authenticity and interpersonal connection in virtual learning and functions as a mediator that strengthens learner engagement.

In summary, Self-Determination Theory (SDT) explains the motivational mechanisms of engagement through the satisfaction of psychological needs, while Social Cognitive Theory (SCT) clarifies the behavioral and environmental dynamics that sustain learning effort [6, 25, 28]. The integration of these two frameworks offers a comprehensive explanation of how self-efficacy (personal belief), teacher emotional support (psychological and social), and social presence (technological and environmental) collectively shape engagement in online mechanical engineering education. This integrated theoretical foundation underpins the development of the study's conceptual model, the Integrated Model of Psychosocial and Technological Predictors of Online Learning Engagement, and guides the formulation of hypotheses to be empirically tested in the subsequent analysis.

1.4 Research Hypothesis

Online self-efficacy reflects students' confidence in their ability to navigate digital platforms, manage learning tasks, and communicate effectively in virtual environments [17]. Drawing from Social Cognitive Theory, self-efficacy influences motivation, persistence, and learning performance by regulating effort and resilience during challenges [30,28]. In online settings, students with higher self-efficacy demonstrate greater initiative, persistence, and satisfaction, leading to deeper cognitive and behavioral engagement [18]. In mechanical engineering, where problem-solving and application-based learning are central, self-efficacy plays a decisive role in sustaining focus and overcoming technological or conceptual difficulties [8]. Accordingly, the following hypothesis is proposed:

H1: There is a significant relationship between online self-efficacy and online student engagement in mechanical engineering learning.

Social presence, defined as the perceived sense of connection and authenticity in online interactions, represents a critical affective factor in digital learning environments [23]. It fosters emotional safety, collaborative learning, and a sense of belonging, all of which are central to maintaining engagement in remote settings [24]. Social Cognitive Theory highlights that environmental cues, such as peer and instructor interaction, reinforce students' confidence and participation through reciprocal social influence [28]. When learners experience a strong social presence, they are more likely to participate actively, express their ideas, and sustain motivation, even in complex courses like mechanical engineering [19]. Hence, the study hypothesizes that:

H2: There is a significant relationship between social presence and online student engagement in mechanical engineering learning.

Teacher emotional support refers to the extent to which instructors demonstrate empathy, provide encouragement, and respond to students' emotional and learning needs [20,22]. Within the framework of Self-Determination Theory, such support satisfies the psychological needs of autonomy, competence, and relatedness [6,21]. Emotional support reduces learner anxiety, enhances self-confidence, and strengthens intrinsic motivation, which collectively lead to higher engagement levels [27]. For mechanical engineering students who often grapple with demanding analytical and practical tasks, teacher empathy and motivational presence can significantly elevate persistence and learning satisfaction [4]. Thus, the following hypothesis is formulated:

H3: There is a significant relationship between teacher emotional support and online student engagement in mechanical engineering learning.

2. Methods

2.1 Research Design

This study adopted a quantitative, cross-sectional survey design to examine the relationships among online learning self-efficacy (OLSE), teacher emotional support (TES), social presence (SP), and online student engagement (OSE) among mechanical engineering undergraduates in China. This design was chosen because it enables the statistical testing of hypothesized associations between psychosocial and technological predictors, consistent with the integrated framework of Self-Determination Theory (SDT) and Social Cognitive Theory (SCT) [37,6]. The study aimed not only to identify significant relationships between constructs but also to establish the psychometric soundness of the measurement instruments through validity and reliability testing. Emphasis was placed on construct-level correlations rather than causal inference, which makes the cross-sectional survey appropriate for this exploratory stage of model validation.

2.2 Population and Sampling

The target population consisted of undergraduate students enrolled in mechanical engineering programs at Guangzhou Vocational College of Technology & Business, a major technical institution in southern China. Mechanical engineering was selected as the focal discipline because it represents a high-cognitive-demand field that has undergone rapid digitalization, posing unique challenges for online engagement [9, 38]. A stratified convenience sampling technique was used to ensure representation across three academic years (Year 1–Year 3) and four mechanical engineering specializations. The inclusion criteria were:

i. Students currently enrolled in at least one real-time (synchronous) online mechanical engineering course,

ii. Having at least one semester of prior online learning experience, and

iii. Willingness to voluntarily participate.

Out of 220 distributed questionnaires, 212 valid responses were obtained, yielding a response rate of 96.4%. The sample size met the general guideline for multivariate analysis (a 10:1 ratio between respondents and indicators), ensuring sufficient statistical power for factor validation and correlation testing.

2.3 Instrumentation

The questionnaire comprised four validated subscales and a demographic section:

i. Online Student Engagement (OSE):

Measured using the 16-item scale by Hoi and Le (2021), capturing behavioral, cognitive, and emotional engagement on a five-point Likert scale (1 = strongly disagree to 5 = strongly agree).

ii. Social Presence (SP):

Adapted from Richardson and Swan [39], this 9-item instrument assesses students' perceived authenticity and connectedness in online interaction.

iii. Online Learning Self-Efficacy (OLSE):

Based on Tsai et al. [32], this 10-item scale measures confidence in managing online tasks, using digital tools, and collaborating in virtual spaces.

iv. Teacher Emotional Support (TES):

Adapted from Romano et al. [40], this 12-item instrument evaluates empathy, encouragement, and responsiveness perceived from instructors.

All items were measured using a five-point Likert scale, with higher scores indicating stronger agreement or greater presence of the construct.

2.3 Validation and Translation Procedure

Because the study was conducted in China, a rigorous translation–back translation procedure was implemented to ensure both linguistic and conceptual equivalence. The English version was first translated into Chinese by a bilingual educational researcher with expertise in engineering pedagogy. A second bilingual expert, unaware of the original version, then retranslated it into English. Discrepancies were reviewed by an expert panel comprising two mechanical engineering lecturers and one educational psychologist, who refined phrasing for cultural clarity and technical accuracy. Subsequently, content validity was evaluated by five field experts who rated the relevance, clarity, and representativeness of each item. The Item Content Validity Index (I-CVI) ranged between 0.87 and 1.00, indicating excellent item-level clarity.

2.4 Pilot Testing

A pilot test was administered to 30 mechanical engineering students who were not part of the main study. Respondents provided written feedback on wording, comprehension, and survey length. Minor revisions were made to reduce redundancy and enhance semantic precision. The pilot data yielded acceptable internal consistency (Cronbach's α values between 0.78 and 0.88), confirming the instrument's reliability prior to full-scale deployment.

2.5 Data Collection Procedure

Data were collected during the Spring 2025 academic semester through the college's official online platform. Students received the survey link via institutional email and course announcements. Each participant was required to read and understand an informed consent statement, ensuring voluntary participation and maintaining anonymity. Respondents completed the questionnaire within approximately 15 minutes. To enhance response quality, participation was scheduled during class hours with the instructor's approval, thereby reducing nonresponse bias. No incentives were provided. All responses were automatically recorded in Microsoft Excel and then exported to SPSS for analysis.

2.6 Ethical Considerations

This study received institutional approval from the Guangzhou Vocational College of Technology & Business. Ethical compliance adhered to the Declaration of Helsinki. Participation was voluntary, and students were informed about data confidentiality, anonymity, and the right to withdraw at any point without academic penalty.

2.7 Data Analysis

Data analysis was conducted using SPSS Version 20 and Microsoft Excel 2023. The analytical process comprised three sequential stages:

i. Preliminary Screening:

Missing values, outliers, and normality assumptions were examined using descriptive statistics (mean, skewness, kurtosis).
ii. Measurement Reliability and Validity:
a. Internal Consistency Reliability: Cronbach's α and Composite Reliability (CR) were computed, with thresholds set at 0.70 and 0.90 respectively [41].
b. Convergent Validity: Evaluated using Average Variance Extracted (AVE) (> 0.50).
c. Sampling Adequacy: Assessed via Kaiser–Meyer–Olkin (KMO) (> 0.70) and Bartlett's Test of Sphericity ($p < 0.001$).
iii. Exploratory Factor Analysis (EFA): Conducted using Varimax rotation to confirm factor dimensionality. Items with loadings below 0.50 were excluded to optimize construct clarity.
iv. Inferential Analysis:
Pearson's correlation analysis (one-tailed) tested hypothesized relationships among constructs, consistent with the directional predictions derived from SDT and SCT frameworks. Bootstrapping (1,000 resamples) was applied to verify the stability of correlation coefficients and 95% confidence intervals.

Although Structural Equation Modeling (SEM) was not performed, the validated measurement model provides a solid empirical foundation for future SEM or path analysis studies in engineering education contexts. The detailed validation, pilot testing, and reliability analyses ensured methodological robustness. High CR values (>0.90) and significant KMO results confirmed the dataset's adequacy for multivariate analysis. The procedures established a transparent, replicable, and ethically sound methodology, aligning with international research standards for cross-cultural education studies [7,9,42].

3. Results

3.1 Reliability and Convergent Validity Analysis

The study examined the reliability and convergent validity of the four latent constructs: Online Student Engagement (OSE), Teacher Emotional Support (TES), Online Learning Self-Efficacy (OLSE), and Social Presence (SP). Table 1 presents the descriptive statistics, Cronbach's α coefficients, Composite Reliability (CR), and Average Variance Extracted (AVE) for each construct.

Table 1. Descriptive **Statistics** and Convergent Validity Results

Variable	Mean	Cronbach's α	CR	AVE
OSE	3.49	0.87	0.9613	0.6246
TES	3.62	0.79	0.9565	0.6133
OLSE	3.31	0.87	0.9535	0.487
SP	2.88	0.65	0.9290	0.5956

Except for Social Presence (SP) with a moderate Cronbach's α (0.65), all constructs demonstrated high internal consistency (α > 0.80). The Composite Reliability (CR) values exceeded 0.90 for all variables, indicating strong indicator reliability and internal consistency. In terms of convergent validity, three constructs (OSE, TES, and SP) achieved acceptable AVE values above the 0.50 benchmark, confirming adequate convergent validity. However, the OLSE scale reported a slightly lower AVE (0.487), implying that a few indicators might have limited explanatory power. Future refinement of this scale is recommended to improve construct precision. Overall, the measurement results affirm that the instruments are reliable and valid for subsequent Confirmatory Factor Analysis (CFA) and Structural Equation Modeling (SEM).

3.2 Sampling Adequacy and Sphericity Tests

To evaluate the suitability of the dataset for factor analysis, Kaiser–Meyer–Olkin (KMO) and Bartlett's Test of Sphericity were conducted. The KMO values for all four scales exceeded 0.70, confirming sampling adequacy, while Bartlett's tests were significant ($p < 0.001$), indicating sufficient inter-item correlations for factor extraction. All scales demonstrated satisfactory sampling adequacy (KMO > 0.70) and significant Bartlett's tests ($p < 0.001$), validating the appropriateness of the dataset for Exploratory Factor Analysis (EFA).

Table 2. KMO and Bartlett's Test Results

Scale	KMO	Approx. Chi-Square	df	p-value
OSE	0.828	1787.328	120	0.000
TES	0.788	1925.280	105	0.000
OLSE	0.873	1863.941	253	0.000
SP	0.750	445.041	45	0.000

3.3 Factor Analysis (EFA) Results

EFA with Varimax rotation was performed to assess the underlying structure of each scale. Items with factor loadings > 0.50 and communalities > 0.50 were retained. The EFA confirmed distinct and coherent factor structures for all four constructs. Most items displayed strong loadings (>0.50) and acceptable communalities (>0.50). However, six items were recommended for deletion to enhance the scales' construct validity and internal consistency before proceeding to CFA.

3.4 Correlation Analysis

To examine the relationships among the constructs, Pearson correlation coefficients were calculated with one-sided significance testing, consistent with the directional hypotheses.

Table 3. Pearson Correlation Results

Variables	TES	OLSE	SP
OSE	.134*	.246**	.571**
Significance (one-tailed)	.026	.000	.000
N	212	212	212

* $p < 0.05$, ** $p < 0.01$

Online Student Engagement (OSE) was positively and significantly correlated with Teacher Emotional Support (TES; $r = 0.134$, $p < 0.05$), Online Learning Self-Efficacy (OLSE; $r = 0.246$, $p < 0.01$), and Social Presence (SP; $r = 0.571$, $p < 0.01$). Among these, the strongest relationship was between OSE and SP, suggesting that students with stronger perceptions of social connectedness tend to exhibit higher engagement in online learning. To verify the robustness of these correlations, bootstrap analysis (1,000 resamples) was performed. The bias-corrected 95% confidence intervals (CI) were as follows:

i. OSE–TES: [−0.003, 0.270]
ii. OSE–OLSE: [0.105, 0.376]
iii. OSE–SP: [0.482, 0.648]

The bootstrap results reconfirmed the statistical stability of the OSE–OLSE and OSE–SP relationships, both of which remained entirely above zero. Although the OSE–TES correlation was positive, its CI contained zero, suggesting a weaker and less stable association. Overall, the results indicate that all four constructs demonstrated acceptable reliability, validity, and factor structure, providing a sound empirical foundation for Confirmatory Factor Analysis (CFA) and

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Structural Equation Modeling (SEM). The strong correlations, particularly between Social Presence and Online Student Engagement, highlight the centrality of social connectedness and emotional support in sustaining engagement within online mechanical engineering learning environments.

4. Discussion

4.1 Teacher Emotional Support and Online Student Engagement

Although teacher emotional support was significantly correlated with online student engagement ($r = 0.134$, $p < 0.05$), the correlation strength was relatively low compared to other variables. This result suggests that while emotional support from instructors contributes to engagement, its influence may be attenuated in technical and practice-intensive disciplines such as mechanical engineering. In such contexts, student engagement is often driven more by task-related motivation, problem-solving demands, and technological facilitation than by affective encouragement. This interpretation aligns with Zhao et al. [40], who reported that in high-technology online courses, the impact of emotional support is secondary to factors such as course design and the quality of interactive content.

Similarly, Shao et al. [28] emphasized that emotional connectedness tends to diminish in large-scale synchronous learning environments, where instructors face constraints in establishing personalized rapport with each learner. In the Chinese higher education context, where online mechanical engineering classes frequently involve large cohorts, teachers may struggle to provide individualized emotional engagement, thereby reducing their measurable effect.

Nevertheless, this finding does not undermine the importance of teacher emotional support; rather, it underscores the need to adapt emotional engagement strategies to the online technological environment. As suggested by Qi et al. [24], integrating digital tools such as personalized video feedback, motivational messages, and interactive office hours could help instructors convey empathy more efficiently, even in large virtual classrooms.

4.2 Self-Efficacy and Online Student Engagement

A moderate, positive, and statistically significant correlation was observed between self-efficacy and online student engagement ($r = 0.246$, $p < 0.01$). This relationship validates the premise of Bandura's Social Cognitive Theory [28], which posits that individuals' beliefs in their capability to accomplish learning tasks directly shape their persistence, effort, and engagement. For mechanical engineering students, self-efficacy is particularly critical due to the complex cognitive and technical demands of their coursework. Learners who perceive themselves as competent in managing simulations, solving design problems, and mastering mechanical systems are more likely to engage deeply in online discussions, complete challenging tasks, and sustain motivation over time.

This finding also aligns with Chang et al. [5], who found that structured feedback loops and stepwise learning scaffolds enhance online self-efficacy, leading to stronger engagement outcomes. In light of this, fostering self-efficacy should be considered a pedagogical priority in online engineering education. Instructors can strengthen learners' confidence by offering incremental challenges, timely performance feedback, and virtual skill-building workshops, enabling students to perceive progress and mastery. These practices, when aligned with SDT's competence dimension, not only enhance cognitive engagement but also promote autonomous motivation and sustained participation.

4.3 Social Presence and Online Student Engagement

Among the three examined predictors, social presence exhibited the strongest correlation with online student engagement ($r = 0.571$, $p < 0.01$), confirming its central role in sustaining active participation in virtual learning environments. This finding corroborates the Community of Inquiry (CoI) framework proposed by Miao et al. [24], which emphasizes that social presence—the perception of others as "real" and emotionally accessible creates a sense of belonging, trust, and interaction that fuels engagement.

In mechanical engineering online courses, strong social presence helps counteract the isolation often associated with self-paced or asynchronous learning formats. Students who experience meaningful peer and instructor interactions are more likely to collaborate on problem-solving, share resources, and maintain continuous participation. These interactions, grounded in both SDT's relatedness need and SCT's environmental reinforcement mechanisms, enhance not only emotional engagement but also cognitive depth.

The present findings are also consistent with those of Hew et al. [11], who demonstrated that enhancing social presence significantly improves learner completion rates and satisfaction in Massive Open Online Courses (MOOCs). This study extends those results to the field of mechanical engineering, confirming that social connectedness is equally essential in technical disciplines, where collaboration and knowledge exchange are integral to professional practice.

4.4 Comparison with Previous Studies

The results offer an important contrast to prior studies conducted in the humanities and social sciences, where emotional support has often emerged as a stronger predictor of engagement. In these contexts, relational and affective factors are more salient to learning outcomes. However, in mechanical engineering, cognitive challenge, technological interactivity, and task relevance appear to play more dominant roles. This divergence is consistent with He et al. [10], who noted that the instructional emphasis in STEM and engineering disciplines shifts toward knowledge mastery, system simulation, and analytical performance, thereby diminishing the relative influence of affective factors.

By integrating SCT and SDT, the present study reaffirms that while emotional and social dimensions remain relevant, technological and self-regulatory competencies hold greater weight in predicting engagement among engineering learners.

4.5 Practical Implications

The findings yield several pedagogical implications for enhancing engagement in online mechanical engineering education. First, strengthening social presence should be a strategic focus. Instructors can incorporate interactive features such as real-time Q&A sessions, collaborative group projects, and peer review mechanisms to foster community and interaction [20].

Second, building self-efficacy through structured feedback, scaffolded tasks, and mastery-oriented assessments can significantly improve learners' confidence and persistence [5]. Integrating simulation-based exercises and gamified performance tracking could further enhance students' perceived competence and engagement.

Third, optimizing emotional support through technology such as personalized video feedback, supportive announcements, or virtual mentorship can make teacher–student interactions more authentic and effective in large-scale online environments [24].

By combining these psychosocial and technological strategies, instructors can cultivate a more holistic online learning ecosystem that balances emotional, cognitive, and behavioral engagement.

5. Conclusions

This study proposed and empirically examined an Integrated Model of Psychosocial and Technological Predictors of Online Learning Engagement among mechanical engineering students in China. Grounded in Self-Determination Theory (SDT) and Social Cognitive Theory (SCT), the research sought to explain how online self-efficacy, teacher emotional support, and social presence collectively influence students' engagement in real-time virtual learning environments.

The results revealed that social presence was the strongest determinant of online engagement, emphasizing the importance of authentic interaction, collaboration, and connectedness in sustaining learning motivation. This finding aligns with Miao et al. [18] and Hew et al. [11], who similarly observed that perceived social connectedness enhances cognitive and emotional participation in online learning by fostering a sense of community and reducing isolation. The significance of social presence is also supported by Ong and Quek [20], who found that interactive course design and peer collaboration substantially improved engagement and persistence in virtual settings. These convergent results reinforce the notion that fostering social presence is crucial in replicating the collaborative and problem-solving culture central to mechanical engineering education.

The study also found a moderate yet significant relationship between online self-efficacy and engagement, confirming that students' confidence in managing digital tools, solving complex tasks, and navigating online systems directly influences persistence and cognitive investment. This finding is consistent with Pan [18] and Zhao et al. [17], who reported that higher self-efficacy leads to stronger self-regulation, greater effort, and deeper learning in online contexts. Similarly, Huang and Kou [25] and Chang et al. [5] noted that competence-based confidence and structured feedback loops are powerful motivators for continuous engagement in digital learning environments, particularly in STEM disciplines where task mastery is central to learning outcomes.

Although teacher emotional support exhibited a weaker correlation, it remained statistically significant, indicating that affective engagement continues to play a role even in technically demanding fields [19]. This nuanced finding echoes the conclusions of Liu and Zhou [22] and Shao et al. [28], who found that while emotional support enhances enjoyment and reduces boredom, its effect is often mediated by the practical and performance-oriented nature of STEM subjects. Similarly, He et al. [10] confirmed that emotional support improves self-efficacy and reduces burnout, though its magnitude depends on the degree of social interaction embedded within course design. These studies collectively affirm that emotional support remains valuable but must be adapted through technological tools such as personalized feedback or virtual mentoring to remain effective in large-scale online environments [24].

Taken together, these findings validate the theoretical proposition that online learning engagement is a multidimensional construct shaped by the dynamic interaction between psychological beliefs and environmental supports. The integration of SDT and SCT provides a comprehensive explanation of how intrinsic motivation (autonomy, competence, and relatedness) interacts with environmental factors such as teacher presence and peer collaboration to promote sustained engagement [6,37]. Moreover, the present study extends recent work by Hu and Xiao [7] and Wang and Pan [20], demonstrating that online engagement in engineering contexts depends not only on system usability or cognitive challenge but also on the social and motivational climate within the learning environment.

From a practical perspective, this study emphasizes that addressing the engagement gap in mechanical engineering requires a balanced integration of psychosocial and technological design principles. Consistent with Ong and Quek [20] and Chang et al. [5], educators should prioritize interactive course structures, real-time collaboration, and scaffolded feedback mechanisms that build both self-efficacy and social presence. Furthermore, the findings align with He et al. [42] and Wang et al. [36], who highlight that integrating emotional, social, and cognitive dimensions into online learning systems leads to more resilient and motivated learners in higher education.

In conclusion, the current research contributes to the interdisciplinary understanding of engagement by empirically demonstrating that technological sophistication alone is insufficient without psychosocial empowerment. The study affirms that students thrive when online environments simultaneously promote confidence, social belonging, and emotional connection. By validating this integrated framework, the research not only advances theoretical discourse in SDT and SCT but also provides actionable insights for designing human-centered, socially connected, and competence-driven online education in mechanical engineering and beyond.

5.1 Theoretical and Methodological Contributions

From a theoretical standpoint, this study extends SDT and SCT by demonstrating their interdisciplinary applicability to the field of engineering education, which is often underrepresented in social learning research. It confirms that while SDT explains engagement through the satisfaction of autonomy, competence, and relatedness needs, SCT provides insight into the reciprocal influence of self-efficacy, environment, and behavior. Methodologically, the study contributes a validated measurement model of online engagement and its psychosocial predictors in the context of mechanical engineering. The instrument demonstrated robust reliability and acceptable construct validity, providing a sound empirical basis for subsequent Confirmatory Factor Analysis (CFA) and Structural Equation Modeling (SEM). By refining and adapting scales across languages and disciplines, this study also enhances the cross-cultural applicability of online education research.

5.2 Practical Recommendations

Based on the findings, several actionable strategies are recommended to enhance online engagement in mechanical engineering education:

i. Enhancing Social Presence: Integrate interaction-driven learning designs such as live discussions, breakout collaboration rooms, and peer evaluation platforms. These activities cultivate belonging, trust, and communication, key elements that increase cognitive and emotional engagement [20].

ii. Strengthening Self-Efficacy: Design learning pathways that build confidence progressively through scaffolded tasks, simulation exercises, and adaptive feedback loops. Providing visible progress indicators and achievement milestones can reinforce students' sense of competence and control [5].

iii. Optimizing Teacher Emotional Support through Technology: Leverage digital media such as personalized video messages, supportive notifications, or virtual mentoring to compensate for the limited interpersonal connection typical of large online classes. Empathetic communication, even when mediated by technology, can enhance the perceived presence of the instructor and relational warmth [24].

iv. Developing Interdisciplinary Online Pedagogy: Collaboration between engineering educators, instructional designers, and educational psychologists should be encouraged to develop online curricula that merge technical rigor with social learning design. This interdisciplinary approach aligns with global trends in technology-enhanced learning ecosystems and supports sustainable engagement [21,2].

5.3 Future Research Directions

Future studies should extend this model across various STEM disciplines and cultural contexts to examine potential moderating variables, such as gender, learning experience, and technological literacy. Longitudinal and mixed-method designs may also reveal how engagement evolves over time and how learners internalize social and emotional factors in sustained online environments. Moreover, integrating learning analytics and eye-tracking technologies could provide real-time indicators of engagement, bridging behavioral metrics with psychological constructs.

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