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Impact of Student-Centred Teaching Strategies on the Development of Metacognitive Components of Adaptive Expertise among Engineering Professionals: A Structural Equation Modelling Approach

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Abstract
Learning is dynamic, interactive and informative process. The present study investigates the impact of student-centred teaching strategies on the development of metacognitive dimensions of adaptive expertise among engineering professionals. In contrast to traditional pedagogical approaches, student-centred methods are explored for their effectiveness in fostering higher-order thinking skills essential for dynamic and complex engineering environments. The research also examines the mediating role of intrinsic motivation in the relationship between student-centred strategies and metacognitive development. A quantitative research methodology was employed, with data collected through structured questionnaires distributed among engineering professionals engaged in professional learning or upskilling environments. The conceptual framework was validated using Partial Least Squares Structural Equation Modelling (PLS-SEM), executed via SmartPLS 4.0 software. The measurement model confirmed the reliability and validity of constructs, while the structural model assessed the hypothesized relationships. Results indicate a significant positive influence of student-centred strategies on metacognitive growth, with intrinsic motivation playing a partial mediating role in this relationship. The findings underscore the pedagogical value of learner-centric teaching in professional engineering education, highlighting its role in developing adaptable, reflective practitioners. The study offers empirical insights for educators, curriculum designers, and policymakers aiming to enhance lifelong learning competencies in the engineering sector.
Keywords: *Metacognition, Student-centred teaching, intrinsic motivation, Adaptive expertise, NEP 2020*

1. Introduction

In the evolving landscape of engineering education, there is a decisive shift toward student-centred teaching strategies that actively foster metacognitive skills crucial for adaptive expertise. Recent studies highlight how flipped and online models with socially shared metacognitive supports significantly enhance learners' metacognitive awareness and intrinsic motivation (Ayvaz-Yazıcıoğlu et al., 2025). Generation Z engineering professionals, growing up as digital natives, especially benefit from metacognitive scaffolding when paired with AI-enhanced pedagogies (Smith & Lee, 2025). Moreover, student-centred approaches have been empirically linked to both academic and personal growth in graduate STEM cohorts, with marked improvements in self-regulated learning and reflective thinking (Garcia et al., 2025). Complementing these findings, Self-Determination Theory positions intrinsic motivation as essential to deepen engagement and internalize metacognitive regulation during complex engineering tasks (Ryan & Deci, 2017, as cited in Ayvaz-Yazıcıoğlu et al., 2025). Thus, this research employs

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Partial Least Squares Structural Equation Modeling to examine how student-centred strategies influence the development of metacognitive dimensions—and how intrinsic motivation mediates this relationship—in engineering professionals. The outcomes aim to provide evidence-based guidance for curriculum designers and educators seeking to cultivate adaptive expertise in modern engineering contexts.

The world economy has shifted its paradigm from traditional to innovative, all-inclusive and user-centred practices. Today's world is fast changing, and so are the demands of various jobs, including engineering professionals. The demands on engineering professionals are ever-increasing, and with the advent of artificial intelligence, professionals have to be really geared up to meet the job demands and stay relevant in the organisation (Gaikwad, 2024). No matter how well one prepares, there is always an element of uncertainty and ambiguity in performing technical jobs. It further leads to the physical as well as digital stress to the concerned users. In order to deal with such uncertainty and unforeseen challenges, the institutions need to focus on appropriate teaching methodologies to sharpen the skills of the modern-day engineering professionals and develop adaptive expertise among them to meet the evolving needs of the job landscape (Gaikwad & Bhattacharya, 2024). This paper aims to address the type of teaching strategies required to develop the needed expertise among the learners to handle uncertainty and ambiguity in their professional domain. Institutions engage many resources aimed at continuous and relevant training for maintaining the relevance of the workforce in their professions (Salas et al., 2012). It needs no emphasis that an appropriately trained workforce is the strong foundation for the successful functioning of the organisation when it meets headwinds or navigates through the choppy waters. It's a mutually beneficial arrangement for both the people and the organisation. The present study focuses on the influence of Student-Centred Teaching Strategies (SCTS) on the development of the Metacognition dimension of adaptive expertise, mediated by the intrinsic motivation of the students.

2. Background of Study

- **Student–Centred Teaching Strategies**

The traditional teaching revolves around the student as a passive participant, and the teacher plays a central role in imparting knowledge. This passive approach has a great hindrance to the student's larger participation in the classroom learning process and impacts the collaborative learning, as the teacher controls the learning proceedings (Aluvalu et al., 2024; Fletcher & Chatelier, 2000). However, student-centered teaching strategies or active learning strategies are aimed at placing the student at the center of learning, and the teacher's role is mainly one of guidance (B. S. Bell & Kozlowski, 2008). This helps the student to have control over the learning and can reflect on the learning process. The active learning approaches consider the student as an active participant in the learning journey and factor in the cognitive abilities of the learner (Vogel-Walcutt, JJ et al. 2013). Some of the student-centred teaching strategies include 'advanced organisers, analogical learning, guided discovery learning, error management training, metacognition training, and mastery-oriented learning, etc.', and they help in fostering the metacognition dimension among the students (Smith et al., 1997). Among other student-centred teaching strategies, problem-based, case-based and project-based learning, guided or pure discovery learning, inquiry-based learning, etc., are popularly adopted (O'Neil, 2014; Prince & Felder, 2006; Pulakos et al., 2002).

Conventional teaching strategies follow a deductive approach, involving teaching of theoretical concepts followed by solving related examples (Prince & Felder, 2006). These strategies result in the development of routine expertise, fostering only procedural

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knowledge (Gamborg et al., 2024). However, student-centred teaching strategies are based on the inductive learning approach in which the knowledge is constructed by the students, and the teacher's role is generic guidance to the students (Bell & Kozlowski, 2008). Therefore, 'constructivist theory' plays a major role in student-centred teaching. Transfer of learning to real-life scenarios is a key advantage associated with student-centred learning, which helps them to handle and resolve complex situations when encountered (McKenna, 2007; Salas et al., 2012). More importantly, instructional guidance is a key factor to be in the mind while adopting teaching strategies, and based on the stage of learning, viz. beginner or advanced, guidance can be implicit or explicit in a scaffolding and adaptive manner (Vogel-Walcutt et al., 2013). Cognitive load should not be overwhelming during the process of learning. The modern-day teaching process should therefore be student-centred to reap the benefits for the students in terms of better learning transfer. Literature review also brings out that student-centred teaching strategies result in the development of metacognition, an important dimension of adaptive expertise, among the students (O'Neil, 2014). The learning environment must aim at contextually supporting the metacognition process (Hattie, Biggs, & Purdie, 1996) as it leads to better learning transfer (Garner & Alexander, 1989; Schraw & Dennison, 1994). More importantly, this results in motivation of the learner and improvement of metacognition in handling uncertain and complex real-life situations (Vogel-Walcutt et al., 2009). The concepts of metacognition as a dimension of adaptive expertise will be discussed in the subsequent sections. Therefore, the present paper considers student-centred learning strategies as the independent variable.

- **Metacognition**

As introduced in the previous section, adaptive expertise is essential for handling unfamiliarity and uncertainty in technical jobs. While routine experts can resolve familiar domain challenges, however, their capabilities would come short when dealing with unfamiliar and novel situations (Hatano & Inagaki, 1986). Thus, adaptive expertise helps invent new procedures based on previous knowledge and helps professionals deal with uncertain situations (Holyoak, 1991). Besides domain and innovation skills, metacognition is an important dimension of adaptive expertise that is essential for handling unfamiliar and ambiguous situations in various jobs (Carbonell et al., 2014). Metacognition is important to the development of adaptive expertise, as seen in the technical R&D domain (Lee, 2022). While domain and innovation skills are familiar, in the context of the present study, the metacognition dimension is considered as a dependent variable. It refers to self-awareness about one's own knowledge, thinking process, task performance, etc. The metacognition concept has two important aspects, one being knowledge or awareness of the thought or cognition, and the second aspect being regulation of the thought (Schraw, 1998; Schraw & Dennison, 1994; Vogel-Walcutt et al., 2009). According to O'Neil (1999), metacognition indicates awareness about one's thought process. It has two important facets. The first one is planning, which means that an individual should have an objective with the proper planning, and the second one is self-monitoring, which means that while achieving the objective, there has to be self-monitoring. Metacognition plays a key part in creating new methods different from the routine ones, and when the work involves generating new methods (Kozlowski et al., 2001). Metacognition helps people to comprehend a circumstance better, reflect on their existing knowledge, and understand the adequacy of their knowledge in handling the situation (Fisher & Peterson, 2001). Metacognition enables students to successfully adapt their mental activities, including comprehension of their skill sets and the ability to apply their skills in different situations (Vogel-Walcutt et al., 2009).

- **Intrinsic Motivation**

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Intrinsic motivation is an internal drive to perform a task because of the inherent enjoyment and fulfilment derived from the task itself, as opposed to seeking external rewards (Ryan & Deci, 2000). Student-centred learning strategies influence the development of metacognition through a self-regulation process (Kozlowski et al., 2001). Self Determination and Cognitive Evaluation Theories bring forth that learner-centred teaching approaches, with mastery orientation rather than performance-based evaluation, influence the development of intrinsic motivation (Ryan & Deci, 2000). Intrinsic motivation is an important element of the self-regulation process. It relates to the student's disposition in the learning process in a self-directed manner (McCombs, 1984). Active or student-centred learning, where the students have certain control in the learning process, promotes self-efficacy and further results in intrinsic motivation (McCombs,1984; Ryan & Deci, 2000), which can help in handling ambiguity and uncertainty in professional jobs. In a study on intrinsic motivation in the physical education profession, it was inferred that the active involvement of the students in the learning process is vital for fostering intrinsic motivation (Ahmed & Dakhiel, 2019; Cocca et al., 2022). Similarly, a study on biomedical students highlights that student-centred learning helps the student to be actively involved and engaged in the learning process, thus enhancing critical thinking and self-motivation (Lees-Murdock et al., 2024). Student-centred learning strategies or active learning strategies influence the students' motivation to learn and help in the transfer of learning, which is the key requirement for the development of metacognition and adaptive expertise (Komarraju, 2008; Quinones, 1995; Salas et al., 2012). Based on the past literature studies, it is evident that intrinsic motivation mediates the relationship between student-centred teaching strategies and metacognition.

3. Significance of Study:

This study is important for engineering education as it addresses the growing need for flexible, reflective, and self-driven professionals in today's fast-changing, technology-focused world. As industries move toward complex problem-solving and innovation, engineers must develop adaptive expertise—not just deep knowledge in their field, but also the ability to apply what they learn in new situations. The study highlights how student-centered teaching methods can help achieve this by encouraging metacognition, which allows students to think about, assess, and adjust their own thinking—a key skill for lifelong learning. Additionally, this research adds to the conversation about educational reform in engineering by exploring how metacognition and intrinsic motivation support deeper learning. It offers practical advice for educators and institutions to create curricula that go beyond technical skills to foster cognitive flexibility and learner independence. By connecting theory with real-world teaching, the study aims to help shape future programs that meet global standards for producing adaptable and innovative engineers.

4. Objectives of Study

- To examine the direct impact of student-centred teaching strategies on the development of metacognitive abilities among engineering professionals
- To assess the influence of student-centred teaching strategies on enhancing intrinsic motivation in engineering education contexts
- To investigate the mediating role of intrinsic motivation in the relationship between student-centred teaching strategies and metacognitive development

5. Literature Review:

Student-centered teaching strategies have become important in engineering and higher education because they help students engage more deeply, think critically, and learn independently. Unlike traditional lecture-based methods, these approaches focus on students by encouraging collaboration, hands-on activities, and inquiry-based learning. Recent studies in engineering education show that methods like flipped classrooms,

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problem-based learning, and reflective assignments boost students' independence and develop higher-level thinking skills needed for real-world problem solving (Tawafak et al., 2023). These strategies align with constructivist theories, which emphasize learning through active participation rather than passively receiving information, making them effective for building adaptable learning skills (Kozan & Richardson, 2023).

Metacognition, or the ability to monitor and control one's own thinking processes, is key to developing expertise. Students with strong metacognitive skills can plan, observe, and adjust their learning strategies to improve outcomes in complex tasks. In fields like engineering, developing metacognition is linked to reflective judgment, self-directed learning, and ongoing professional growth. Research shows that student-centered environments encourage metacognitive reflection through peer discussions, feedback, and self-assessment activities (Rahimirad et al., 2023). These practices help learners apply their skills to new and unexpected challenges, which is crucial in today's fast-changing engineering roles.

Intrinsic motivation, which is the internal drive to learn for personal satisfaction and growth, plays a vital role in knowledge and skill development within student-centered settings. Based on Self-Determination Theory, intrinsic motivation is nurtured by teaching strategies that support student autonomy, which then boosts engagement and metacognitive skills (Chen et al., 2025). In STEM education especially, motivation and metacognition work together closely—motivated students are more likely to set meaningful goals, use effective learning strategies, and stick with challenges (Yen et al., 2025). Combining motivation and metacognition in student-centered teaching offers a strong approach to helping engineering students develop adaptive expertise.

6. Research Methodology

- **Conceptual Framework**

A conceptual framework was developed for testing the aforementioned theory, and the same is reflected in Figure 1. This paper aims to quantitatively test the conceptual model consisting of student-centred teaching strategies (SC) as the independent variable, metacognition (MC) as the dependent variable, and intrinsic motivation (IM) as the mediating variable, using Structural Equation Modelling (SEM) in Smart PLS4.

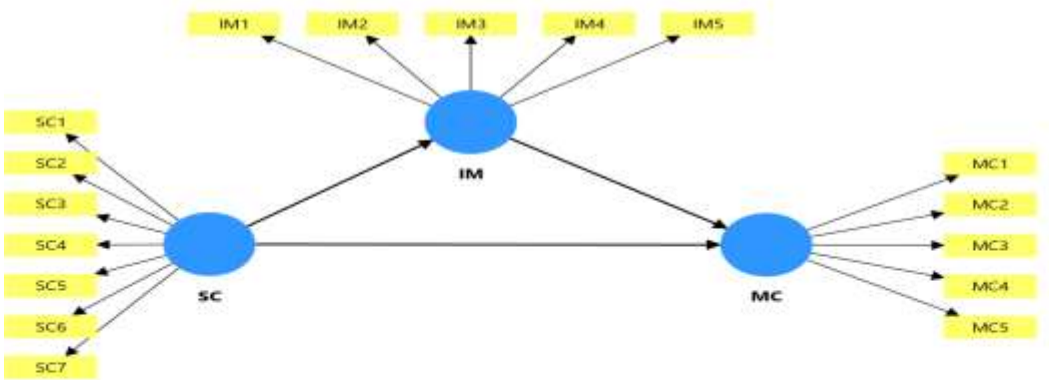

Figure 1. Conceptual Model in Smart PLS

- **Hypotheses of Study:**

The proposed null hypotheses in the present study are listed below:

(a) **$H_0$1**. There is no significant relation between Student-Centred Teaching Strategies and Metacognition of the trainees.

(b) **$H_0$2**. There is no significant relation between Student-Centred Teaching Strategies and Intrinsic Motivation of the trainees.

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(c) **H0 3**. There is no significant relation between Self-efficacy and Metacognition of the trainees.

- **Data Collection**:

Data collection was based on a survey questionnaire administered to a total of 126 engineering teaching professionals in the colleges. Out of the 126 professionals, only 96 were considered for the data analysis after data cleaning. The survey questionnaire is based on a 5-point Likert scale. The content validity of the questionnaire was checked based on discussions and useful inputs provided by the respondents in the pre-survey. The measurement scale for SC with seven indicators has been adapted from the scale developed by Eristi B & Akdeniz C (2012), under the subcategory of 'focus strategies.' The measurement scale for MC with five indicators has been adapted from the scale developed by Carbonell et al. (2014). Finally, the measurement scale for IM with five indicators has been adapted from the scale developed by McAuley et al. (1989).

7. Data Analysis

The quantitative analysis was undertaken using smart PLS 4 software. The analysis involved validation of the 'Measurement Model', followed by assessment of various parameters of the 'Structural Model'.

- **Measurement Model Analysis**

Important parameters of the measurement model, pertaining to indicator loading, validity measure using convergent validity, and reliability measure using composite reliability, are populated in Table 1. Discriminant validity readings are populated in Table 2. The measurement model analysis indicates strong factor loading (Λ) values for all, except for three factors of MC, the lowest being 0.645, which are very close to the reference threshold values of 0.7 (Hair et al., 2019). However, they are retained since none of these values are below the lowest threshold value of 0.4, and satisfy the condition of reliability and average variance values threshold limits of 0.708 and 0.5, respectively (Hair et al., 2019). Hence, all the indicators are retained for the analysis, as they meet the reference criterion. The reliability measure is indicated by the alpha coefficient (Cronbach α) and Composite Reliability (CR). The reliability values of all variables reflected in Table 1 are well above the reference threshold value of 0.7. Average Variance (AVE), which indicates convergent validity, is well above the threshold reference value of 0.5 (Hair et al., 2019). Also, discriminant validity values indicated in Table 2 are less than the threshold value of 0.85 as per the Heterotrait-Monotrait ratio (HTMT) criterion (Hair et al., 2019). Therefore, the measurement model is validated.

Table 1. Item loadings, reliability and convergent validity

	Λ	α	CR	AVE
Student-Centred Teaching Strategies		0.929	0.943	0.702
SC1	0.739			
SC2	0.824			
SC3	0.828			
SC4	0.902			
SC5	0.883			
SC6	0.866			
SC7	0.813			
Metacognition		0.756	0.835	0.505
MC1	0.714			
MC2	0.690			
MC3	0.663			
MC4	0.645			

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MC5	0.827			
Intrinsic Motivation		0.929	0.899	0.643
IM1	0.886			
IM2	0.851			
IM3	0.807			
IM4	0.751			
IM5	0.700			

Table 2. Discriminant Validity (HTMT)

	LC	MC	IM
SC			
MC	**0.869**		
IM	0.856	**0.800**	

- **Structural Model Analysis**

Bootstrapping results of the structural model are represented in Figure 2. As a first step, the Variance Inflation Factor (VIF) values of the structural model have been analysed. The analysis brings out that all the VIF values of the endogenous variables are less than the threshold limit of 3 (Hair et al., 2019), the highest value being 2.465. Hence, collinearity issues are ruled out. The other parameters of the structural model analysis are summarised in Table 3. It indicates R^2 values of 0.594 and 0.586 for IM and MC, respectively. Even the adjusted R^2 values of .590 and .577 indicate that the model's predictive power is more than moderate (Hair et al., 2019), and goodness of fit for the conceptual model is validated.
Bootstrapping results highlighting beta coefficients, standard deviation, significance, t-values and bias-corrected CIs are shown in Table 3. The results support all the alternate hypotheses, H1, H2, and H3. It is therefore evident that the student-centred teaching strategies positively and significantly influence metacognition. Further, it is also seen that student-centred teaching strategies positively and significantly influence intrinsic motivation, and intrinsic motivation positively and significantly influences metacognition. Path analysis in Figure 2 also supports these hypotheses. As summarized in the mediation results in Table 4, this is a case of complementary mediation, which indicates that student-centred teaching strategies have a significant effect on the development of metacognition, mediated through intrinsic motivation.

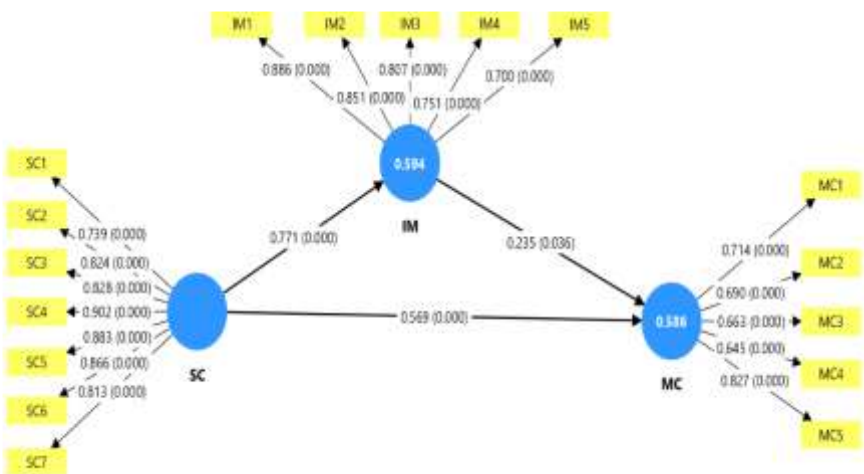

Figure 2. SEM Bootstrapping of the model with Path Coefficients and p-values

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Table 3. Results of structural model analysis

Hypotheses	Relationship	β	SD	t-value	Confidence Interval (bias corrected)		Decision
					5%	95%	
H1	SC->MC	0.569	0.132	4.327	0.331	0.770	Supported
H2	SC->IM	0.771	0.049	15.669	0.670	0.838	Supported
H3	IM->MC	0.235	0.131	1.803	0.023	0.452	Supported
	R^2	R^2 adj					
IM	R^2 =0.594	0.590					
MC	R^2 =0.586	0.577					

Table 4. Summary of mediation results

Total effect (SC->MC)		Direct effect (SC-MC)		Indirect effect of SC on MC			
β	p-value	β	p-value	β	SD	t-value	p-value
0.751	0.000	0.569	0.000	0.182	0.102	1.787	0.037

8. Findings of Study:

- **Student-Centred Teaching Strategies significantly influence Metacognition:**

The path coefficient for the relationship between SC and MC (β = 0.569, t = 4.327) is statistically significant at the 95% confidence level, as the confidence interval (0.331 to 0.770) does not include zero. This confirms Hypothesis H1 and demonstrates a strong positive influence of student-centred teaching on metacognitive development among engineering professionals. The result suggests that instructional strategies promoting active learning, reflection, and learner autonomy effectively enhance metacognitive awareness and regulation.

- **Student-Centred Teaching Strategies strongly predict Intrinsic Motivation:**

The path coefficient for the SC to IM relationship (β = 0.771, t = 15.669) is highly significant, supported by a tight confidence interval (0.670 to 0.838) that confirms Hypothesis H2. This finding reveals a very strong direct impact of student-centred strategies on boosting intrinsic motivation in learners. It implies that when learners are actively engaged in their learning process and are given autonomy and collaborative opportunities, their internal drive to learn and succeed increases substantially.

- **Intrinsic Motivation positively influences Metacognition with partial mediation:**

The IM to MC path (β = 0.235, t = 1.803) is statistically significant at the 90% confidence level, as the confidence interval (0.023 to 0.452) is above zero. This supports Hypothesis H3 and indicates that intrinsic motivation serves as a partial mediator between SC and MC. While its effect is moderate compared to the direct impact of SC on MC, intrinsic motivation still plays a meaningful role in facilitating

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metacognitive growth by encouraging learners to reflect and self-regulate their thinking processes.

- **Variance explained in the model reflects strong predictive power:**

The coefficient of determination (R^2) for Intrinsic Motivation is 0.594 (adjusted R^2 = 0.590), indicating that 59.4% of the variance in intrinsic motivation is explained by student-centred teaching strategies. Likewise, Metacognition shows an R^2 value of 0.586 (adjusted R^2 = 0.577), meaning 58.6% of the variance in metacognitive development is accounted for by both SC and IM combined. These R^2 values reflect a high explanatory power of the proposed model, affirming the robustness of the conceptual framework used in this study.

9. Conclusion

This study has discussed that student-centred teaching strategies have an edge compared to traditional teaching strategies in that the learner is placed at the centre of learning and the teacher acts as a guide in facilitating the learning process. These strategies help in the development of an important dimension of adaptive expertise, i.e. metacognition, which is helpful in handling ambiguity and uncertainty in real-life situations for professional engineers. Through a quantitative study, it has been established that student-centred teaching strategies positively and significantly influence metacognition, through the mediating influence of intrinsic motivation. As a future study, it is recommended to test this theory across multiple dimensions of adaptive expertise in other professional disciplines to incorporate active learning strategies in the curriculum.

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