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**Problem-Based Learning with Management  
Consulting Methods: A Pedagogy for Critical  
Thinking in Higher Education**

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## ABSTRACT

This research aims to address the critical gaps in critical thinking skills highlighted by the World Economic Forum and the National Association for Colleges and Employers, which reveal a disparity between employer expectations and graduate preparedness. By developing and evaluating Problem-Based Learning with Management Consulting Methods, this study seeks to enhance critical thinking education through combining management consulting with engaging problem-based learning in a culturally responsive pedagogy tailored for a diverse cohort. The research assesses the effectiveness of this approach using the California Critical Thinking Skills Test and explores variables such as gender and private/public high school education. This study employs a mixed-method design, combining longitudinal quantitative research ( $n = 177$ ) from 18 nationalities with qualitative analysis of anonymous student questionnaires collected by the university's central research unit from 2023 to 2024. Quantitative outcomes are benchmarked against the meta-analysis by Huber and Kuncel (2016). Results indicate that a single semester of treatment is as effective as four years of traditional education to improve critical thinking skills, while multiple treatments with less than a one-year gap demonstrate even greater improvements.

Key words: Critical Thinking; Problem-Based Learning; Consulting Methods; Business Education; STEM Education; Interdisciplinary Education

# 1. INTRODUCTION

Critical thinking (CT) is increasingly recognized as the paramount competency for the 21st century, consistently ranked as vital by global employers. The World Economic Forum's Future of Jobs Report 2025 identified analytical critical thinking skills (CTS) as the most in-demand skill for the 2025-2030 workforce, based on a survey of 1,000 employers representing 14 million workers across 55 economies (WEF, 2025). In contrast, the National Association for Colleges and Employers (NACE, 2024) revealed that while 94.9 percent of employers consider CT extremely essential for new hires, only 66.1 percent of graduates meet this standard, indicating a critical education-to-industry gap.

For decades, education systems worldwide have grappled with this challenge. In the United States, initiatives like the No Child Left Behind Act (2001) and the Partnership for 21st Century Skills (Capps et al., 2005; P21, 2019) have prioritized CT, integrating it into the widely recognized "4Cs" framework: critical thinking, creativity, communication, and collaboration (Alismail & McGuire, 2015; Tohani & Aulia, 2022). Despite the widespread adoption of Problem-Based Learning (PBL) in business schools, empirical validation of its effectiveness remains limited (Savery, 2015; Thorndahl & Stentoft, 2020).

Cultural dynamics further complicates CT pedagogy. In Confucian-influenced and high power-distance cultures (Hofstede, 2011), students who hesitate to challenge authority, may be misconstrued as disengaged (Chan et al., 2011; Lucas, 2019; Tan, 2017; Tian & Low, 2011; Tiwari et al., 2003). Research on culturally responsive CT instruction for these learners is sparse (Dong et al., 2023).

Conversely, the management consulting industry effectively trains graduates in CT methodologies, such as hypothesis-driven analysis and MECE (Mutually Exclusive, Collectively Exhaustive) analysis, to cultivate effective problem-solvers for an industry

valued at over \$500 billion. Notably, these methodologies are absent from STEM education, despite their alignment with scientific reasoning and employer demand for analytical skills in technical roles.

This study bridges critical gaps in CT education by developing and evaluating Problem-Based Learning with Management Consulting Methods (PBL-MCM), a pedagogical framework that integrates problem-solving with management consulting methods while incorporating latest technologies, business strategies, culturally responsive learning and teaching theories, and student motivation methods. Samples under study are 70 percent Hong Kong and 30 percent international students from 18 nationalities.

This research contributes to CT education through the introduction of the PBL-MCM, supported by evidence from the California Critical Thinking Skills Test (CCTST). This pedagogy features a scaffolded curriculum of two courses with multiple treatment exposures across four 13-week semesters over two years and examines two demographic variables: gender (male/female) and high school type (private/public). Quantitative findings are benchmarked against the meta-analysis by Huber and Kuncel, which reviewed 10,000 studies from 1963 to 2011 (Huber & Kuncel, 2016). Qualitative findings from two years of anonymous Student Feedback Questionnaires (SFQ) are analyzed and correlated with quantitative findings. Recommendations for adapting PBL-MCM to various curricula while maintaining pedagogical integrity are also included.

Theoretical contributions include insights into dose-response relationships in CT interventions, cultural influences on CTS development, and effective integration of MCM into academia. Implementation guidance spans five key dimensions: classroom technology, curriculum design, learning theory, instructional methods, and student motivation strategies.

## **2. LITERATURE REVIEW**

### **Critical Thinking**

Socrates is a pivotal figure in CT, renowned for his Socratic method, which emphasizes inquiry through questioning and dialogue. His student, Plato, expanded these ideas, emphasizing dialectical reasoning and the pursuit of truth through rational thought. Aristotle further advanced CT by formalizing logic and advocating for empirical observation as essential to knowledge acquisition (Stonehouse et al., 2011). René Descartes significantly influenced CT by introducing skepticism and methodological doubt, encapsulated in his famous assertion, “Cogito, ergo sum” (“I think, therefore I am”). This approach encouraged reliance on reason, laying the groundwork for modern scientific inquiry (Hatfield, 2017).

In the 20<sup>th</sup> century, philosopher John Dewey described CT as “the kind of thinking that consists in turning a subject over in the mind and giving it serious consecutive consideration” (Dewey, 1933). Dewey proposed that when students engage with problems - grappling with the conditions presented and actively seeking their own solutions – they stimulate their inherent curiosity, foster learning, and promote CT.

The 1980s witnessed a transformative shift in CT research, moving toward practical application and skills development. Pioneering this approach, philosopher and educator Robert Ennis framed CT as an intentional, self-directed process requiring individuals to rigorously examine their own thought patterns while systematically evaluating claims, beliefs, arguments, and evidence with clarity and logical precision to minimize bias and preconception (Ennis, 1985, 1989). Central to Ennis’s work is the principle that CT functions as a teachable cognitive skill – one that strengthens through deliberate practice and structured training. Researchers generally agree that CT is a teachable skill that can be learned through

intentional instruction and is distinct from creative thinking. However, there has been a lack of consensus among researchers on its definition (Birgili, 2015; Wechsler et al., 2018).

Recognizing the need for a consensus definition of CT to guide collaborative educational reform efforts in the United States, the American Philosophical Association (APA) convened the Delphi Project in 1988. The resulting Delphi Report defines CT as both a mindset and a set of cognitive skills. The CT mindset encompasses an attitude of being open and fair-minded, inquisitive, and flexible as well as willingness to entertain diverse viewpoints. The CTS consists of cognitive activities of analyzing arguments, making inferences of hidden information by use of inductive or deductive reasoning, and making decisions or judgments to solve a problem (Liu et al., 2014) (Lai, 2011). In short, the APA's definition of CTS developed by the Delphi project consists of the ability to conduct analysis, inference, evaluation, induction, and deduction.

Complementing APA's CT definition, commercial tests were developed under the leadership of Facione, include the California Critical Thinking Skills Test (CCTST), and the California Critical Thinking Mindset Indicators (CCTDI) (Facione, 1990). CCTST has been used tool for higher education program evaluation and accreditation, graduate school admission, military and emergency response evaluation, and corporate talent acquisition (Facione, 2011).

### **Critical Thinking Education in Higher Education**

In international education literature, observations of Asian students' reserved classroom behaviors often lead to the perception that they lack CTS, as they typically do not exhibit behaviors such as interrupting the instructor to ask a question, express opinions, or challenge ideas. While self-expression and engagement in debate are not explicitly defined in the formal CT definitions, Asian student's reserved behavior in the classroom is often seen as indicators of low CTS (Durkin, 2008; Lee & Carrasquillo, 2006).

Despite this perception, students from Asian tiger countries - such as Japan, South Korea, China, Hong Kong and Taiwan – have consistently excelled in academic achievement tests like the Trends in International Mathematics and Science Study (TIMSS) and the Program for International Student Assessment (PISA) (Guhn et al., 2024; İdil et al., 2024). This observation highlights a significant gap in teaching methodologies: CT education, often grounded in Western philosophies, must be adapted to suit students raised within different philosophical frameworks. Such adaptations are crucial for fostering CTS among university students from diverse backgrounds.

### **Problem-Based Learning**

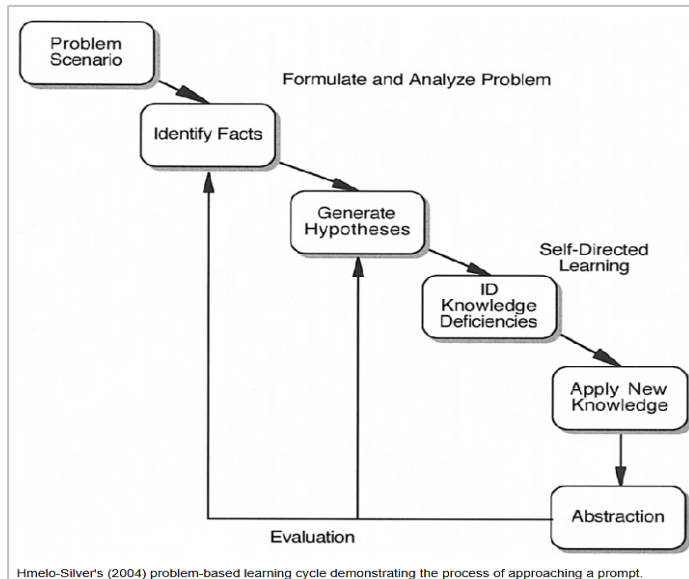
The theoretical foundation of problem-based learning (PBL) is rooted in the Constructivist approach to education (Davydov, 1995; Dewey, 1938; Wadsworth, 1996). Constructivism emphasizes the learners' active participation and knowledge-building through firsthand experience. PBL is a learner-centric, experiential approach that contrasts sharply with traditional teaching methods, where teachers lecture while students passively receive information.

PBL was first utilized in the 1920s by Harvard University through its two Case Methods.

The first method, inspired by philosopher Dewey, was implemented at the Harvard Business School (Fraser, 1931). The second method, developed by Dean Christopher Columbus Landell at the Law School in 1970s, was later adopted by Harvard Medical School. The case method used in these institutions employ an inductive method of reasoning approach, drawing comparisons between cases to address real-life business problems – often less defined than those in law and medicine.

By the time Canada's McMaster Medical School was founded in 1966, the case method had gained popularity, largely due to Bill Spaulding's efforts to incorporate PBL into the

curriculum (Spaulding, 1991). Neurologist Howard Barrows joined McMaster in 1968, further advancing PBL by using trained actors as patients and “problem-boxes” for simulation (Barrows et al., 1968). His influential work established him as the founding father of PBL (Neufeld & Barrows, 1974), and the theoretical model of PBL is shown in Figure 1.



*Figure 1. Barrow's Theoretical Model of PBL (Hmelo-Silver, 2004, p.237)*

This shift in medical education mirrors the broader theoretical foundations of Constructivism, empowering students to engage with realistic clinical scenarios and better preparing future healthcare professionals to apply knowledge and CTS in real-world situations (Yu et al., 2013). Today, medical training typically include two to three years of PBL during clinical rotations, with several nursing schools using the CCTST to assess program effectiveness due to the clinical nature of CTS in nursing (Yu et al., 2013).

Researchers generally agree that all varieties of PBL share five characteristics (Barrows, 2000; Barrows & Tamblyn, 1980; Evensen et al., 2000; Hmelo-Silver, 2004; Lu et al., 2014; Newman, 2003; Newman, 2005; Ungaretti et al., 2015):

1. Instructor as Facilitator: the instructor guides the learning process rather than simply delivering knowledge.
2. Explicit Problem-Solving Process: PBL uses a defined process to facilitate learning through problem-solving activities.
3. Ill-Structured, Real-World Problems: PBL addresses complex, challenges requiring multidisciplinary learning.
4. Collaborative, Team-based Approach: Team collaboration is essential to address ill-structured problems from multiple perspectives.
5. Inclusion of Clearly Defined Learning Objectives & Assessment Methods: This aspect, contributed by Newman, adds structure and transparency to PBL (Newman, 2003; Newman, 2005).

### **Problem-Based Learning Education in Higher Education**

In 2011, Hallinger and Lu studied PBL adoption in management education in Thailand, finding that students rated PBL courses positively, particularly for engagement and action-directed learning, with a significant fixed effect of 0.14 ( $p < .05$ ) on engagement. However, there were no significant gains in overall course or instructor effectiveness compared to traditional methods, as the study relied on student perceptions rather than standardized tests to measure critical thinking (CT) skills.

In the same year, Jippes proposed that instructors working in “high power distance cultures” need to take a scaffolding approach to help students proceed through a problem-based curriculum, emphasizing the importance of culturally relevant materials (Jippes & Majoor, 2011).

A 2021 bibliometric review by Hallinger and Kovačević revealed that PBL is gaining traction in emerging regions, particularly in Asia (Hallinger & Kovačević, 2021). However, they also

discovered that Hofstede's cultural dimension of "power distance" poses significant barriers to PBL implementation in and Eastern European and Asian societies. They called for future research to explore design principles and impact of PBL curricula in these regions.

Overall, existing literature research indicates that students transitioning from a teacher-centered education to a PBL-based approach require scaffolded support, with content that is relevant to learners' cultural settings rather than solely relying on materials from western cultures.

### **Management Consulting Methods**

Management consulting has evolved into a multi-billion global industry within a span of 150 years, valued at USD \$550 billion in 2012 and growing at 4.2 percent CAGR (Gross, 2012). The field's theoretical foundation draws from business, science and behavioral psychology (Kipping, 2003). Firms like McKinsey have shifted from providing ad hoc advisory services to systematic, data-driven methods and knowledge-sharing practices that the market is willing to pay (Gross & Poor, 2008; McKenna, 1995). This raises the question of why engineering and sciences programs do not incorporate management consulting methods in their undergraduate and postgraduate curricula.

Management Consulting Methods (MCM) includes structured problem-solving frameworks and engagement management methodology that provide clear guidelines for analyzing diverse business problems. To achieve a holistic understanding of a client's situation, consultants conduct a situation analysis, which involves collecting and synthesizing relevant information to fully comprehend the client's operational context and challenges. One common tool used in problem analysis are MECE frameworks with attributes of "Mutually Exclusive, Collectively Exhaustive" to ensure a comprehensive yet non-duplicative coverage

of factors of the problem space (Lee & Chen, 2018). Notable MECE frameworks include McKinsey's 7S Model and Porter's Five Forces Model, both of which guide consultants to analyze broadly and deeply for insights into organizational dynamics for multidimensional analysis (Grundy, 2006; Nejad et al., 2015; Peters & Waterman Jr, 2011; Porter, 1997).

Translating the situation analysis process in APA Delphi Project's definition of CTS, consultants begin an engagement by analyzing and evaluating the situation. When faced with missing information, consultants employ inference, induction and deduction to "connect the dots" and piece together fragmented information. This process aims to establish a coherent understanding of the situation.

Furthermore, the engagement management methodology outlines the processes and best practices for managing projects involving clients, ensuring effective project planning, efficient communication, stakeholder management, and the delivery of consulting services. By leveraging consultants' CTS and problem-solving methods while adhering to established management consulting methodologies, consulting firms strive to provide valuable insights and solutions to their enterprise clients.

### **Management Consulting Methods Education in Higher Education**

Despite the high value of CTS in consulting and 150-year track records, many universities do not teach consultative problem-solving. While leading MBA programs integrate management consulting frameworks into their curricula, undergraduate STEM programs rarely include consulting methods. This is concerning, as students need to practice solving real-world problems using their engineering or scientific principles to address the education-to-industry gap.

Knowledge-hungry students realize they need to practice case-solving to improve their chances for employment with leading firms, many of which utilize case interview for talent

screening (Cheng, 2012). Consequently, forward-thinking students often form student-led consulting clubs to practice case pitching as a means of preparing for highly sought-after career opportunities in consulting and investment banking, both of which have adopted case interviews in their talent screening processes (Cheng, 2012; Kent et al., 2023).

Unfortunately, few undergraduate business and STEM programs formalize consultative problem-solving methods that address contemporary cases involving advanced technologies within a credited course led by faculty. These courses typically lack a structured teaching approach and assessment rubrics. While some universities offer PBL courses for undergraduates, the clients are typically local small companies with straightforward organization structures and decision-making processes.

An exception is a consulting course developed by the researcher for business and STEM undergraduate students, which employs the PBL-MCM pedagogy. This course involves the application of management consulting methods, business strategies and advanced technologies (e.g., eVTOL, AI/ML, LLM) for Fortune 100 companies. The PBL-MCM pedagogy will be further elaborated in the experimental design section of this study.

### **Empirical Works on Critical Thinking**

In 2016, Huber and Kuncel published a meta-analysis of 71 studies on gains in CTS among university students primary from North America, Europe and Australia (Huber & Kuncel, 2016). This analysis included approximately 16,185 longitudinal participants and 9,392 cross-sectional participants in the period from 1963 to 2011. They found evidence that gains were larger across longer time frames and that gains are nonlinear during the four years of college study. Outcomes of this study are benchmarked against Huber and Kuncel's findings as summarized in Table 1.

*Table 1. Summary of CCTST Longitudinal Studies (Huber & Kuncel, 2016, p.9)*

Length of Study (years)	Cohen's d [lower bound, upper bound]
0.5	0.00 [-0.44, 0.44]
1	0.03 [-0.41, 0.47]
2	0.12 [-0.32, 0.57]
3	0.26 [-0.18, 0.71]
4	0.46 [0.01, 0.90]

### **3. RESEARCH METHODOLOGY**

This study examined the central research question: “What is the impact of single versus multiple PBL-MCM course treatments on the CTS of undergraduate students?” To address this question, the following null hypotheses were investigated:

- $H_{0,1}$ : One PBL-MCM treatment does not enhance CTS.
- $H_{0,2}$ : CTS gains are unaffected by the time gap between PBL-MCM treatments.
- $H_{0,3}$ : CTS gains are unaffected by gender (male/female)
- $H_{0,4}$ : CTS gains are unaffected by high school type (public/private).

## 4. RESEARCH FINDINGS AND DISCUSSION

### Overview

The researcher developed and refined the PBL-MCM pedagogy over a decade, integrating Problem-Based Learning with Management Consulting Methods (PBL-MCM). The longitudinal study employed an explanatory sequential mixed methods design, comprising two phases:

- Quantitative phase: the California Critical Thinking Skills Test (CCTST) in pre-post assessments, followed by statistical analysis examines both pre-post differentials (CTSD) and standardized effect sizes (Cohen's d) for comparative benchmarking against established CT education (Huber & Kuncel, 2016).
- Qualitative phase: Thematic analysis of open-ended responses from Student Feedback Questionnaires (SFQs) provided insights into students' experiential perceptions of the PBL-MCM methodology.

This sequential integration of methods ensures that qualitative exploration is informed by preliminary quantitative findings, enabling targeted investigation of emerging patterns.

Details of the PBL-MCM pedagogy, which is the experiment design, will be elaborated upon.

### Experimental Design: PBL-MCM Pedagogy

There are two courses using the PBL-MCM pedagogy in a scaffolded manner. The first course focuses on applying Technology and Management (TM) strategies for case analysis and product design, which differentiate it from traditional case analysis courses offered by the business school. The second course employs students as consultants to address complex challenges faced by a global Fortune 500 firm using TM strategies. The PBL-MCM

pedagogy includes classroom technology, curriculum design, teaching methods, learning theories and student motivations. Each aspect will be explained in detail.

### **PBL-MCM Pedagogy: Classroom Technology**

Blended-learning classroom technology is pivotal for PBL-MCM courses, promoting active learning through remote and local interactions. Classrooms feature whiteboards on all walls and retractable projector screens, facilitating student engagement. Projector sources include a lectern computer and wireless screen sharing from devices, allowing the instructor to move around freely. Rollable chairs and tables support quick reconfiguration for group work, and power sockets are available for students' use throughout the classroom. Ceiling-mounted video cameras, microphones, and speakers enable remote participation and teleconferencing, allowing corporate sponsors to engage without traveling to campus.

### **PBL-MCM Pedagogy: Curriculum Design**

The first course is divided into two halves. The first half emphasizes structured problem-solving using MECE frameworks with brief written cases, titled "TM Case Analysis", while the second half focuses on designing products or services for startups, "TM Product Innovation". Given 35 percent of startups fail due to issues such as poor business models, lack of business development, and lack of product-market-fit (Cantamessa et al., 2018), CTS are vital for addressing these challenges. The second course uses students as consultants to solve a contemporary problem for a Fortune 500 client. This course uses the McKinsey Consulting Engagement Methodology (Friga, 2008), which can be adapted to various industries. Students apply frameworks tailored to specific problems, such as the COM-B framework for behavioral change to reduce paper waste (Willmott et al., 2021), and Swim Lane framework for digital transformation of time-consuming tedious repeated tasks within

work processes (Waterhouse, 2021). The 13-week curriculum progresses through three phases:

- Phase 1: Project Preparation (four weeks) – framing and organizing the project.
- Phase 2: Data Collection (four weeks) – conducting research and analysis.
- Phase 3: Synthesis and Pitching (five weeks) – integrating findings and presenting them to stakeholders and finally, the executive decision-makers.

Figure 2 shows the consulting engagement process used in the second course next to Barrow’s PBL framework to demonstrate alignment.

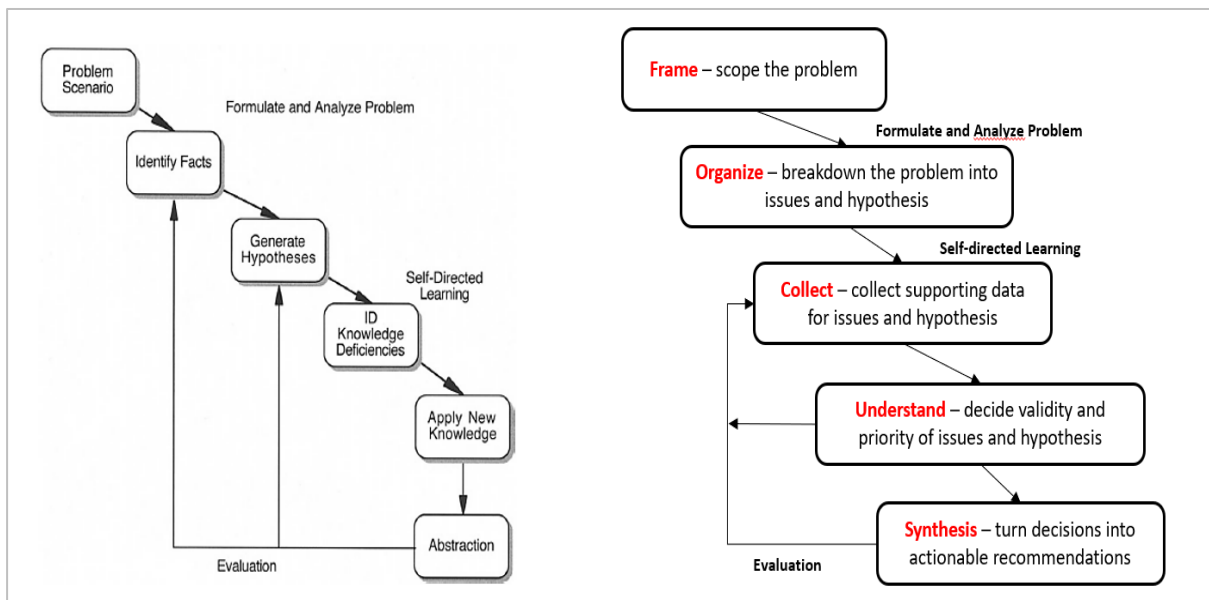


Figure 2. Comparing PBL-MCM Consulting Engagement Process with Barrow's PBL Process (Hmelo-Silver, 2004, p.237)

### PBL-MCM Pedagogy: Learning Theories and Teaching Methods

A core teaching method in the first course is Gradual Release of Responsibility (GRR) models (Fisher & Frey, 2021), which involves four progressive phases: (1) focused instruction, (2) guided instruction, (3) collaborative learning and (4) independent learning.

Following this GRR model, each new MECE framework is repeated three times in the classroom, culminating in a take-home assignment for independent learning. The second half of the first course incorporates frameworks like the Value Proposition Canvas and Business Model Canvas frameworks (Osterwalder & Pigneur, 2010; Osterwalder et al., 2015). The GRR learning model is also applied for each concept in the product design process.

### **PBL-MCM Pedagogy: Student Motivation**

Students are motivated by acquiring practical skills applicable in professional development. For instance, a case analysis cheat sheet for the written exam in the first PBL-MCM course, “TM Case Analysis and Product Innovation”, helped one student to receive an internship offer on the spot when the interviewer saw the richness of cheat sheet contents. Several teams have repurposed the product design for competitions, winning awards and entry to startup incubation programs. In the second PBL-MCM course, “TM Consulting for an Enterprise Client”, students tackle real-world challenges faced by global leading firms, exploring innovative solutions like eVTOLs (i.e., autonomous drones that can transport people and cargo) for low-altitude-economy opportunities. At the beginning of the course, hardly anyone in the course had heard of eVTOL other than the aerospace engineering students. By the end of the course, everyone grew in confidence to solve problems involving unfamiliar technologies and business domains. Students also gain unique discussion topics during interviews giving them competitive advantages in the job market. These engaging projects enhance resumes and provide compelling discussion points during interviews.

### **Instrumentation**

This research utilized an explanatory sequential mixed-method design comprising two phases. The first phase involved a quantitative analysis using paired t-tests with the CCTST administered on student volunteers before and after the PBL-MCM treatments. Statistical

analyses calculated the effect sizes of one treatment using data from the first and second courses, while also examining the second treatment with time gaps of longer than or shorter than one-year from the first treatment. Additionally, demographic subgroups were analyzed by gender and type of school (private/public). ANOVA and multivariable regression analyses were conducted to find correlation between the independent variables.

The second phase involved qualitative analysis of free-form course feedback collected through student feedback questionnaires (SFQs) administered at the end of each semester by the university's central research unit. Thematic analysis utilizes an open-source tool, such as QDA Miner Light, to analyze qualitative data and reveal student perceptions of the PBL-MCM experience, thereby enriching the quantitative findings.

### **Participants**

The study examined 177 students across four offerings of the first course and four offerings of the second course between January 2023 and December 2024. A 77 percent participation rate yielded 63 valid pairs for the first course and 46 pairs for the second course. Participants in the prerequisite course were primarily early-career students, with 63 percent in their first year and 27 percent in their second. In contrast, the consulting course featured advanced students, with half in their third to fifth year. This design allowed for meaningful comparisons of PBL-MCM efficacy across first treatment, second treatment, and second treatment further analyzed by two categories of time gaps and demographic variables.

### **Data Collection and Analysis Procedure**

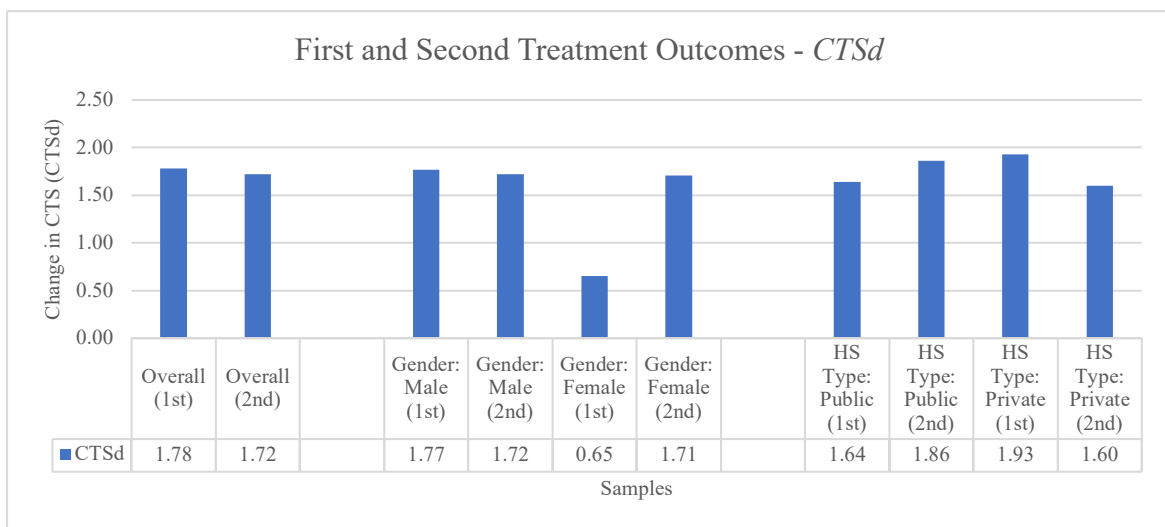
To initiate the quantitative data collection process, the researcher informed students during the first week of the semester about the research and its goals during the course introduction. All students enrolled in the first and second PBL-MCM courses were invited to participate voluntarily via mass email. The email explained the rationale for participation, protection of

their personal data, and the opportunity to gain experience through two pre-paid CCTST tests valued at US \$30. At the end of the semester, during week 13, a reminder email was sent to all students in the course to take the post-test, using the same CCTST login credential assigned for the pre-test.

## 5. CONCLUSION

### Outcomes from the First and Second PBL-MCM Treatments

Both the first and second treatment groups demonstrated a significant improvement. To contrast the performance of overall and subgroups after the one treatment using the prerequisite course and one treatment using the second course, their results are shown side-by-side in Figure 3 and 4.



*Figure 3. First and Second Treatment Outcomes – CTSD of Subgroups*

Figure 3 illustrates the outcomes from the first and second treatments as *CTSD* (change in CCTST scores). Abbreviation “(1<sup>st</sup>)” represents “(1<sup>st</sup> Treatment)”, and “(2<sup>nd</sup>)” denotes “(2<sup>nd</sup> Treatment)”. Samples are grouped as an overall category, two subgroups by gender (males/females), and two subgroups by high school type (public/private).

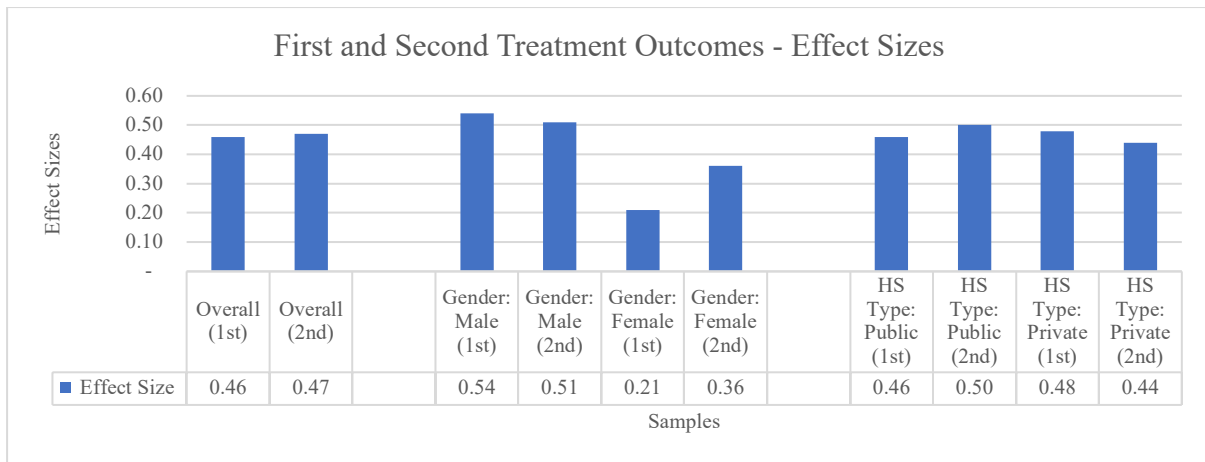


Figure 4. First and Second Treatment Outcomes - Effect Sizes of Subgroups

Figure 4 illustrates the same outcomes from the first and second treatments as effect sizes. Samples are grouped similarly into an overall category, two gender subgroups (males/females), and two high school type subgroups (public/private). ANOVA and multivariable regression analysis of the outcome versus the two independent variables - gender and high school type - revealed the relationship between them and the outcomes are too complex to be predicted using mathematical models and will not be presented here.

#### Interpretations from the First and Second PBL-MCM Treatment Outcomes

Overall, the first treatment samples exhibited a gain in CCTST scores and medium effect size ( $n = 64$ ,  $CTSD = 1.78$ ,  $d = 0.46$ ). Similarly, the second treatment samples also produced a strong outcome ( $n = 46$ ,  $CTSD = 1.72$ ,  $d = 0.47$ ). When compared to Huber and Kuncel's findings in Table 1, these results are on par with a four-year traditional CT education program ( $d = 0.46$ ). These results provide evidence to reject the null hypothesis  $H_{0,1}$ , which posits that one treatment does not enhance CTS.

When analyzing each treatment groups by gender, males showed similar levels of gains after the first treatment ( $n = 54$ ,  $CTSD = 1.77$ ,  $d = 0.54$ ) as the second treatment ( $n = 39$ ,  $CTSD = 1.72$ ,  $d = 0.51$ ). In contrast, females achieved smaller gains after the first treatment

( $n = 9$ ,  $CTSD = 0.65$ ,  $d = 0.21$ ) but matched their male peers after the second treatment ( $n = 7$ ,  $CTSD = 1.71$ ,  $d = 0.36$ ). Notably, males and females had nearly identical gain after the second treatment (1.72 vs 1.71). These outcomes suggest that while females may face initial challenges with the PBL-MCM pedagogy, they perform on par with males after the second treatment, providing partial evidence to reject the null hypothesis ( $H_{0,3}$ ) regarding gender influence.

When analyzing the first treatment samples by school type, students from private schools performed slightly better ( $n = 30$ ,  $CTSD = 1.93$ ,  $d = 0.48$ ) than those from public schools ( $n = 33$ ,  $CTSD = 1.64$ ,  $d = 0.46$ ). However, the opposite trend was observed in the second treatment, where public school students ( $n = 21$ ,  $CTSD = 1.86$ ,  $d = 0.50$ ) achieved better results than those from private schools ( $n = 25$ ,  $CTSD = 1.60$ ,  $d = 0.44$ ). These mixed results suggest that while private school may have an initial advantage, this is equalized after two treatments. Therefore, the null hypothesis ( $H_{0,4}$ ) stands, as there is no strong evidence that private schools provide students with an edge in CTS.

### **Interpretations of the Second PBL-MCM Treatment by Time Gap**

To analyze whether the duration of the time gap between treatments affects outcomes, samples in the second treatment were utilized. Since the first treatment is a prerequisite for the second, samples in the second treatment that also participated in the first treatment had a time gap of less than one year. The remaining samples in the second treatment had a gap longer than one-year. Figure 5 illustrates the 46 samples in the second treatment split into two subgroups by the time gap: over one year and under one year. The outcomes are presented overall, as well as by subgroups of gender (males/females) and school type (private/public).

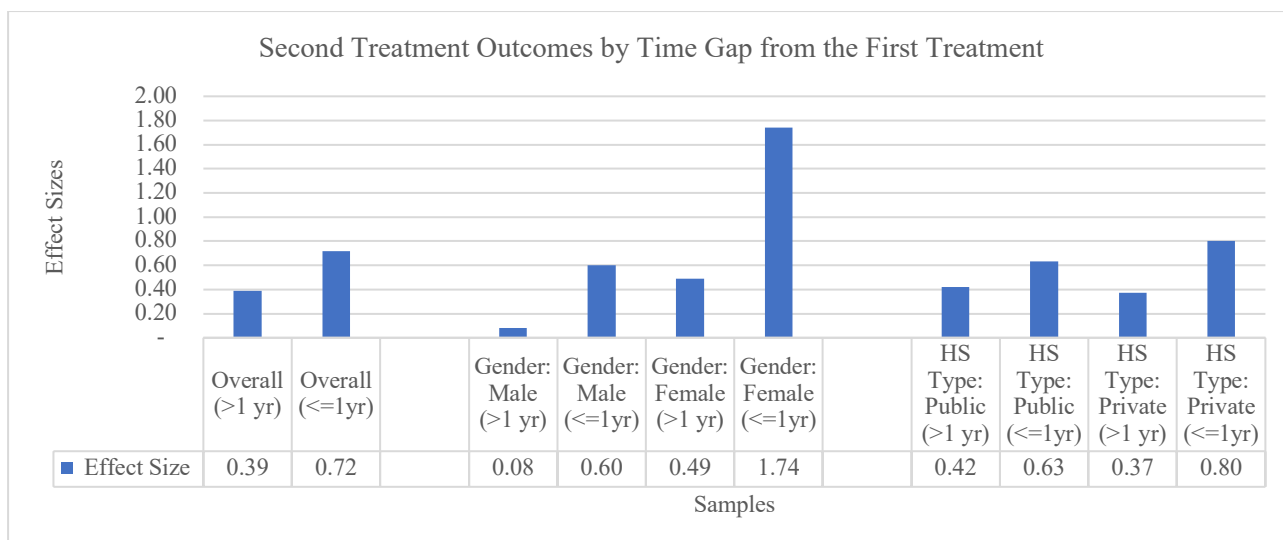


Figure 5. Second Treatment Outcomes Analyzed by Time Gap from the First Treatment

In Figure 5, the abbreviation “<= 1yr” and “>1 yr” denotes shorter and longer than one year for describing the time gap between treatments. Out of the 46 samples, 31 students had a time gap greater than one year, and 15 students had a shorter than one year. Students with a short time gap ( $n = 15$ ,  $CTSD = 2.27$ ,  $d = 0.72$ ) outperform those with time gap longer than one year ( $n = 31$ ,  $CTSD = 1.45$ ,  $d = 0.39$ ).

When analyzing the same 46 students by gender, there were 39 males and 7 females. Among the 37 males, those who receive two treatments with a gap under one year ( $n = 12$ ,  $CTSD = 2.00$ ,  $d = 0.60$ ) outperformed those with longer gap ( $n = 27$ ,  $CTSD = 1.59$ ,  $d = 0.49$ ). For the 7 females who receive the second treatment with a shorter gap ( $n = 3$ ,  $CTSD = 3.33$ ,  $d = 1.74$ ), their performance exceeded those with a longer gap ( $n = 4$ ,  $CTSD = 0.50$ ,  $d = 0.08$ ).

When analyzing the same 46 students by school type, there were 21 students from public schools and 25 from private schools. Among public school students, those receiving two treatments with a shorter gap ( $n = 8$ ,  $CTSD = 2.50$ ,  $d = 0.63$ ) outperformed those with longer gap ( $n = 13$ ,  $CTSD = 1.46$ ,  $d = 0.42$ ). For private school students, those with a shorter gap ( $n = 7$ ,  $CTSD = 2.00$ ,  $d = 0.80$ ) also outperformed those with a longer gap ( $n = 18$ ,  $CTSD = 1.44$ ,  $d = 0.37$ ).

These results indicate that time gap between treatments significantly impacts the efficacy of the PBL-MCM approach. Therefore, the null hypothesis ( $H_{0,2}$ ), which posits that time gap does not impact outcomes, can be rejected.

### **Summary of Hypothesis Findings**

The study provides evidence that both single and multiple PBL-MCM treatments enhance CTS among students from diverse backgrounds. The following conclusions address hypotheses:

- *H<sub>0,1</sub> (One treatment cannot enhance CTS): Rejected.* The empirical data robustly rejected the null hypothesis, demonstrating that PBL-MCM serves as a powerful pedagogical intervention for CTS development. A single PBL-MCM treatment using the prerequisite course produced medium effect sizes ( $d = 0.46$ ), confirming its efficacy in enhancing CTS. Similarly, the second treatment where students consulted for a Fortune 500 enterprise client further strengthened gains ( $d = 0.47$ ), reinforcing the intervention's value. These effect sizes, comparable to traditional four-year CT education benchmarks, underscore the efficiency of this innovative teaching methodology.
- *H<sub>0,2</sub> (Time gap between treatments cannot make an impact): Rejected.* Temporal analysis revealed striking differences in treatment efficacy based on implementation scheduling. Students receiving two treatments within one year showed significantly larger effect size ( $d = 0.72$ ) than those with gaps greater than one year ( $d = 0.39$ ). This pronounced disparity highlights the cognitive benefits of maintaining pedagogical continuity and suggests optimal neural consolidation occurs when concepts are reinforced within compressed timeframes.

- *H<sub>0,3</sub> (CTS gains are unaffected by gender): Rejected.* Longitudinal tracking uncovered important gender dynamics in CTS acquisition. While female students achieved lower *CTSd* after the first treatment compared with male peers (males: *CTSd* = 1.77, females: *CTSd* = 0.65), females caught up after the second treatments with almost identical *CTSd* (males: *CTSd* = 1.72, females: *CTSd* = 1.71). This trajectory suggests that the iterative structure of PBL-MCM provides valuable support in helping female students overcome initial barriers.
- *H<sub>0,4</sub> (CTS gains are unaffected by high school type): Not Rejected.* Contrary to prevailing assumptions about educational privilege, analysis revealed no significant relationship between school type (public vs. private) and ultimate CTS development. Although elite public-school students entered with slight advantages, both groups ultimately achieved comparable effect sizes (public: *d* = 0.46; private: *d* = 0.48), with the gap widening after the second treatment (public: *d* = 0.50; private: *d* = 0.44). These findings challenge conventional wisdom about the superior preparation of private school graduates in higher-order thinking skills.

### **Qualitative Research Findings**

There were four offerings of the first course and four offerings of the second course between 2023 to 2024, with the university's central research unit conducted SFQ at the end of each course. Qualitative data analysis of the anonymized free-text answers to question number eight in the SFQ revealed six key themes reflecting important aspects of students' experience. Figure 6 displays the frequency of common themes identified in the SFQs collected after the first and second PBL-MCM treatments.

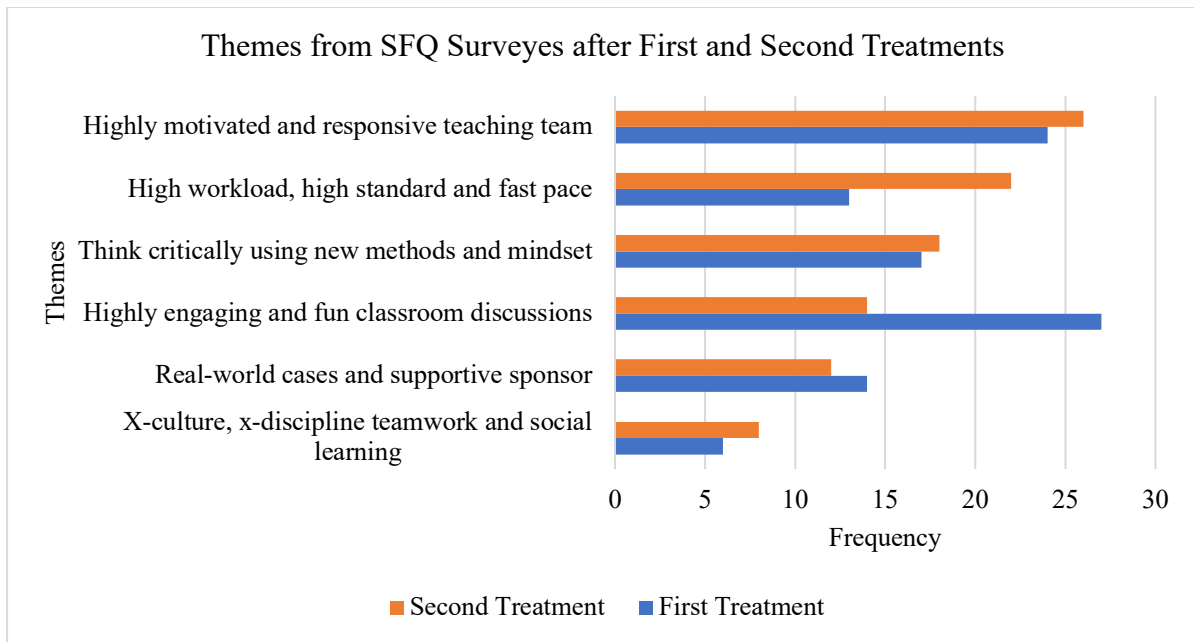


Figure 6. Student Feedback Questionnaires Comment Themes after Treatments

Figure 6 summarizes six key themes that captured significant aspects of the students' experiences after the two course treatments. Interpretation of each theme is elaborated below.

- Theme 1: Highly Motivated and Responsive Teaching Team - This theme reflects students' perception of the quality and dedication of the teaching team, as well as their responsiveness to student queries and the turnaround time for grading assignments.
- Theme 2: High Workload, High Standards, Fast Pace - This theme relates students' perception of the effort required to meet the challenges set before them and quality expectations compared to other courses.
- Theme3: Think Critically Using New Methods and Mindset - Students value the introduction of innovative problem-solving tools and techniques, as well as new mindsets applicable to their future endeavors. This aspect of the courses helped them develop essential skills for tackling complex challenges.

- Theme 4: Cross-culture Teamwork and Social-learning – Students greatly appreciate the opportunity to collaborate with peers from diverse disciplines and countries. This collaborative environment enriched peer learning and fostered broader understanding through varied perspectives.
- Theme 5: Highly Engaged, Challenged and Fun - Students recognized the engaging and interactive nature of the courses, which promoted lively discussions and encouraged active participation. This dynamic atmosphere contributed significantly to their overall learning experience.
- Theme 6: Realistic Challenging Cases with Supportive Sponsor - Students valued the chance to engage with real-world problems, whether through case studies in the prerequisite course or tackling complex challenges with an industry-leading organization over the semester. This practical approach enhances their learning and application of concepts.

Overall, these themes provide valuable insights into the factors that contribute to student satisfaction and success. The findings underscore the importance of responsive teaching, collaborative learning, engaging pedagogies, and practical applications in fostering a positive educational experience. Addressing the concerns related to workload and pacing will be essential for enhancing the overall effectiveness of the courses offered.

## **Discussion**

### **Quantitative Experiment: Findings and Implications**

The findings from the PBL-MCM treatments demonstrate their effectiveness in enhancing critical thinking skills. Both treatments, each lasting one semester which is less than half year, showed comparable impacts ( $d = 0.46$  and  $0.47$ ) to traditional four-year CT education ( $d$

= 0.46). This suggests that curriculum designers should seriously consider integrating the PBL-MCM approach into their programs.

Interestingly, female students entered both courses with similar baseline critical thinking scores to their male counterparts. Although males exhibited higher initial gains, females effectively closed this gap by the second treatment. This indicates the importance of fostering an encouraging environment where female students can adapt to the pedagogy without hesitation.

Furthermore, students from top-tier public high schools exhibited critical thinking scores comparable to those from private institutions. This highlights the value of strong government policies and community support in public education, suggesting that investment in public schools can yield significant benefits for all students.

The study also emphasizes the need for careful calibration of the time gap between treatments to prevent the loss of prerequisite training benefits. Establishing a timeline for enrolling in subsequent courses could enhance the efficacy of the PBL-MCM approach.

### **Qualitative Experiment: Findings and Implications**

The qualitative analysis revealed a complex relationship between perceived workload and value. While 42 percent of students described the workload as "excessive relative to credits," a significant 78 percent rated the courses among their "most valuable university experiences." This paradox highlights the need for instructors to communicate the long-term benefits of rigorous coursework at the start of the semester to manage student expectations.

Longitudinal tracking uncovered that students who initially felt stressed by the "high standards, fast pace" later regarded this pressure as "professionally formative." About 65 percent of respondents credited live consulting projects with helping them develop resilience

and time-management skills, which have proven invaluable in internships and graduate studies.

Cultural differences in workload perception were also evident, particularly among international students from Southeast Asia, who were 2.3 times more likely to frame the workload critically compared to local peers. This suggests that educational backgrounds influence how students perceive challenges, indicating a need for differentiated support strategies that consider cultural contexts.

## **Conclusion**

In summary, this study demonstrates that both single and multiple PBL-MCM treatments significantly enhance CTS among a diverse student population. The rejection of several null hypotheses indicates that these pedagogical approaches not only boost CTS but also reveal important insights about the influences of gender, educational background, and cultural context on performance. The unexpected findings highlight the potential for tailored pedagogies to bridge achievement gaps, particularly for traditionally disadvantaged groups. By integrating the insights gained from this study, educators can refine instructional strategies to better prepare students for the demands of the 21<sup>st</sup> century culture and work ethics, ultimately improving overall educational outcomes.

## **Recommendation for future research**

- **Longitudinal Studies:** Investigate the durability of CTS gains over three to five years, particularly examining whether disadvantaged groups maintain their achieved parity.
- **Dosage Optimization:** Develop protocols for ideal treatment intervals and intensities.
- **Technology Integration:** Explore blended learning models to reduce perceived workload through AI-assisted feedback, maintain engagement in online collaborations,

and scale effective practices to larger cohorts, enabling more students to benefit from opportunities to collaborate with leading companies.

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