Pedagogical Approaches and Course Modality Affecting Students' Self-efficacy and Problem-Solving Attitudes in a TRIZ-Oriented Course

Harshika Singh, Hannah Nolte, Niccolo Becattini

Pedagogical approaches and course modality affecting students' self-efficacy and problem-solving attitudes in a TRIZ-oriented course

Harshika Singh[1][0000-0003-1522-0113], Hannah Nolte[2][0000-0003-2545-8424] and Niccolo' Becattini[1] ✉ [0000-0002-1641-3796]
[1]Politecnico di Milano, Italy [2] The Pennsylvania State University, USA
niccolo.becattini@polimi.it

Abstract. Teaching TRIZ to students who are unfamiliar with it is vital as it assists in spreading a systematic approach to problem-solving in the design and production domain. Typically, the capability to use TRIZ proficiently is measured as a tangible output in the form of exams and project-based activities. However, understanding the impact of using TRIZ on students' self-efficacy and problem-solving attitudes is a good proxy indicating how likely students will persevere using this approach to solve problems despite their initial failures and motivations to get creative solutions. Therefore, the purpose of the study is to understand the effect of TRIZ-oriented courses on students' self-efficacy and problem-solving attitudes towards design activities with respect to the change in the pedagogical approach (traditional and project-based learning) and course modality (in-person and remote). Data was collected at the beginning and end of the course for three different academic years. In general, the results show that project-based learning produces higher self-efficacy in students during a TRIZ course. However, traditional learning improves self-efficacy more than project-based learning. Additionally, in traditional learning, the students' perception of their problem-solving attitudes at the end of the TRIZ course was higher. Regarding course modality, the remote modality of the TRIZ course produced greater increases in students' engineering design self-efficacy than the in-person mode. TRIZ educators can benefit from these results and better estimate the opportunities and limitations due to the implementation of innovative pedagogical approaches in TRIZ courses.

Keywords: TRIZ teaching, Project-based learning, Self-efficacy, Problem-solving attitude, Remote collaboration, In-person collaboration, Pedagogical approaches

1 Context, background and research questions

Understanding student self-efficacy and problem-solving attitudes in engineering courses is fundamental to helping students succeed. Students' self-efficacy and problem-solving attitudes can indicate students motivation [1, 2], engagement [2, 3], and performance [4, 5]. While previous research identified that a TRIZ-oriented course can improve students self-efficacy and problem-solving attitudes [6], more research needs to be conducted to understand how pedagogical approach and course modality impact both of these factors.

Increasing students' self-efficacy, including their engineering design self-efficacy, has been linked to many positive outcomes. Bandura [7, 8] defined self-efficacy as an individual's belief in their ability to successfully perform the behaviours required for a specific performance outcome. In terms of engineering and engineering design, students' self-efficacy refers to their confidence in their ability to do engineering and engineering design tasks like ideating a creative solution to an ill-defined problem. Student self-efficacy has been associated with enhanced engagement [3], increased motivation [1], improved Grade Point Average [9], and more promising perceived career options [10]. Specifically, in engineering, student self-efficacy promotes academic achievement [4], mathematical performance [4], entrepreneurial intention [11], and women's persistence to continue in engineering [12]. Understanding the impact of course design on engineering student self-efficacy is paramount to students' success.

Problem-solving attitude has been shown to predict students' performance [5] and motivation to participate [2]. An attitude is a student's predisposition to respond positively or negatively to a concept based on their emotions, behaviours, and beliefs associated with that concept [5]. Previous research has found that cooperative teaching is more effective in improving students' problem-solving attitudes compared to conventional teaching [13]. In engineering, a problem-solving teaching strategy that offered supplemental instructional materials similarly increased students' problem-solving attitudes and led to increased abilities [14].

Courses with a TRIZ (Russian acronym for the Theory of Inventive Problem Solving) [15] component are beneficial in engineering as they teach a systematic approach to creativity and problem-solving [16]. Previous research has shown that TRIZ can improve students' self-efficacy [6, 17–19], thinking [20], problem-solving abilities [20], and problem-solving attitudes [6]. However, what is currently unknown is the impact pedagogical approach and course modality will have on student outcomes in courses with a TRIZ component.

While most courses have been taught using a traditional learning (TL) lecture-based approach, project-based learning (PBL) offers students the opportunity for hands-on learning. The theory underlying PBL asserts that students learn more through real-world, hands-on projects than they do from traditional coursework [21]. A review of PBL found that PBL has positive affective, cognitive, and behavioural outcomes for students [22]. Previous research has found that PBL courses [23] and assessments [24] increase students' self-efficacy in engineering. Furthermore, PBL has also been found to positively impact problem-solving attitudes [25]. The current study will investigate how incorporating PBL into a course with a TRIZ component impacts students' self-efficacy and problem-solving attitudes.

In addition, the COVID-19 pandemic forced many traditionally in-person courses to go to a remote modality. This drastic change in course delivery and student collaboration likely impacted student outcomes. This study will explore the self-efficacy and problem-solving attitude differences for a TRIZ-oriented PBL course in-person and remotely. A review of factors contributing to self-efficacy in online learning found many unique factors to online education that impact students' self-efficacy [26]. Also, previous research found that group-based problem solving, either online or in-person, improves individuals' problem-solving attitudes [27].

Research questions (RQ) and Contribution

This study will compare Project-based learning (PBL) to traditional learning (TL) to understand how the pedagogical approach affects students' self-efficacy and problem-solving outcomes for a course with a TRIZ component. Additionally, this study will evaluate how a change in course modality, in-person to remote, also impacts those factors. Specifically, this work will answer the following research questions:
RQ1: What is the effect of pedagogical approaches on self-efficacy and problem-solving attitudes of students in TRIZ-oriented class?
RQ2: What is the effect of teaching modality on self-efficacies of students in TRIZ-oriented class?
The results of this research will help educators to more accurately evaluate the impact of instructional choices on students for engineering courses with a TRIZ component.

2 Method

2.1 Set-up

The experiments were set up for the three academic years to monitor the self-efficacy and problem-solving attitudes of the MS students in a Mechanical Engineering course on Methods and Tools for Systematic Innovation (6 ECTS - UNI omitted for review). The course was widely influenced by TRIZ, the Russian acronym for the Theory for the Solution of Inventive Problems [15] and OTSM-TRIZ, the Russian acronym for the General Theory of Powerful Thinking [28].

The overall purpose of the course was to improve students' conceptual design abilities both in terms of divergent and convergent thinking, as needed to run an efficient problem-solving process. The students were introduced to ENV and OTSM-TRIZ functional models [29] to describe entities and functions. Su-Field and OTSM-TRIZ contradictions enabled the description of problems, while the Network of Problems enabled their management [30]. Beyond more analogy-based methods (e.g. Bio-inspired analogies), the heuristics for problem-solving included the 76 Standard solutions, the separation principles to tackle TRIZ contradictions, and ARIZ [29].

The course took place with a similar content structure (very small topic adaptations across the editions) since AY2012-13. What mostly changed in these years is the pedagogical approach used to teach the students. In AY2012-13 the class had ex-cathedra theoretical and practice lectures, thus following a traditional teaching approach. More recently (e.g., AY2019-20 and AY2020-21), the course blended the traditional approach with PBL activities, which included a company that proposed design themes/task to the students who worked in teams. These teams were under the supervision of the teaching staff and company experts and had regular design reviews during the semester. The outbreak of the COVID-19 pandemic also required the lectures and the project activities for the AY2020-21 to take place remotely. In terms of the composition of the class, during AY2012/13 there were 31 students (30M-1F), in AY2019-20 40 students (38M-2F), and in AY2020-21 42 students (38M-4F).

2.2 Measures

All survey measures can be seen in Table 1.

Table 1 Overview of the experimental design and the measures used

Research Questions	Academic Year	Survey Setting	Main content
RQ1: Compare A and B	2012-13	Traditional learning (TL)	**A** Self-efficacy (SE) and problem-solving (PS) attitude questions as used in [6]
	2019-20	Project-based learning (PBL) & In-person instruction	**B** Self-efficacy and problem-solving attitude questions as used in [6]
RQ2: Compare C and D			**C** Engineering design self-efficacy (EDSE) questionnaire designed for engineering design as used in [31]
	2020-21	Project-based learning (PBL) & Remote instruction	**D** Directly asked engineering design self-efficacy question using the definition from the questionnaire design for engineering design students [31]

The survey for parts A and B was the same. Questions for this portion of the questionnaire came from Becattini and Cascini [6] and focused on collecting information about students' self-efficacy and problem-solving attitudes specifically related to TRIZ-oriented courses [6]. This portion had a total of 14 questions, with questions 1-6 measuring self-efficacy and questions 7-14 capturing problem-solving attitudes. Questions were formatted as a 4-point numerical Likert-type scale and a full list of the 14 questions can be seen in Becattini and Cascini [6]. The survey corresponding to part C of the questionnaire focused on collecting Engineering Design Self-Efficacy (EDSE). This part C survey was taken from Carberry et al. [31]. However, the scale of the questions was changed from a 10 to 4-point numerical Likert-type scale, where 1 was minimum and 4 was maximum self-efficacy to match the scale of the part A/B questions.

In the part C survey, EDSE was shaped by four self-concepts (confidence, motivation, expectation, and anxiety) across eight common engineering design stages as recognized by Carberry et al. [31]. The results of parts A/B and part C are comparable in this work as the questions in parts A/B covered many of the same aspects of self-efficacy, such as confidence, motivation, expectation, and perceived success, as part C.

Part A and B will be compared to address RQ1 and part C and D will be used to address RQ2. The definition of self-efficacy provided in part D (Table 1) was based on Carberry et al. [31], which makes the results of part C and D comparable.

2.3 Data collection

For the AY2012-13, data collection took place at the beginning and at the end of the class in order to check the differences between students' ex-ante and ex-post scores. The written questionnaire contained questions related to self-efficacy and problem-solving attitude [6]. The changes in students' skills and their self-perceptions of these skills should be due to their exposition to the topics presented during the semester as well as the practice exercises they did during the lectures. The lectures and practice sessions were held in class and there was no project work activity for AY2012-13.

For the AY2019-20, when the course introduced a significant part of PBL, data was collected twice in the form of an online questionnaire at the beginning and end of the course. During this semester students worked in-person in teams on a design project. There were 10 teams with four students on each team. The online questionnaire had two sets of questions (part B and C from Table 1). The same set of survey questions was used as AY2012-13 to understand how students' self-efficacy and problem-solving attitudes change according to pedagogical approaches (i.e., TL and PBL). Additionally, part C [31] was included in the online questionnaire because it is commonly used to measure students' EDSE when conducting a hands-on design activity.

Similar to AY2019-20, the course for AY2020-21 also utilized PBL. Data was again collected twice in the form of online questionnaires at the beginning (ex-ante survey) and at the end of the course (ex-post survey). However, due to the COVID-19 pandemic, instruction and coursework were completed remotely. A total of 15 student teams consisting of four individuals a team completed the design project. The questionnaire for this study was shortened to prevent additional stress on students during the pandemic. This shortened questionnaire had a direct question that asked students to rate their self-efficacy on a five-point numerical Likert scale, where 1 was the minimum and 5 was the maximum. A clear definition of self-efficacy based on the Carberry et al. [31] definition was included to help students make an accurate rating. Additionally, the questionnaire also had questions related to socio-emotional aspects of team collaboration, which are out of the scope of this paper.

3 Results and discussion

Data collected from three academic years was analyzed using the Python programming language and its data science libraries. An alpha level of 0.05 was used to assess significance.

3.1 The Effect of Pedagogical Approach

Students’ average self-efficacy rating at the beginning of the year was compared to their self-efficacy at the end of the year for each year for the part A and B survey. It can be seen in Fig. 1 that students’ mean self-efficacy for the TL course (AY2012-13) improved significantly (W[1]= 52.5, p< 0.001). TL students’ mean self-efficacy at the end of the year was significantly higher (M= 0.58, SD=0.17) compared to the before the semester values (M= 0.48, SD= 0.15). For the PBL course (AY2019-20), students’ self-efficacy was also found to be significantly different (W= 4.0, p= 0.016). In PBL students’ self-efficacy increased from the beginning of the course (M= 0.60, SD= 0.11) to the end of the course (M= 0.65, SD= 0.10). Additionally, PBL was found to better increase students self-efficacy compared to TL (Point-biserial r= 0.3, p= 0.003 as seen in Fig. 2). Therefore, while both courses improved students’ self-efficacy, these results indicate that PBL is more effective in improving students’ self-efficacy in a TRIZ-oriented course. Students’ increased self-efficacy in the PBL version of the course likely indicates that the project component of the course offered a mastery experience, vicarious experience, or verbal persuasion [7] component that was more effective at increasing students’ self-efficacy. Previous studies have also found that PBL effectively increases student self-efficacy [23, 24].

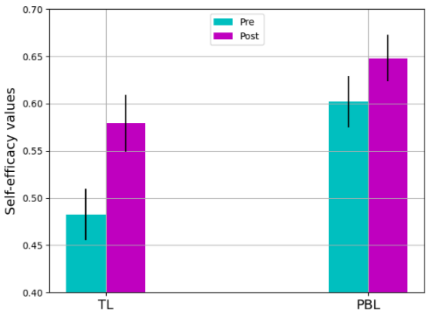

Fig. 1 Mean self-efficacy for TL and PBL (normalized values)

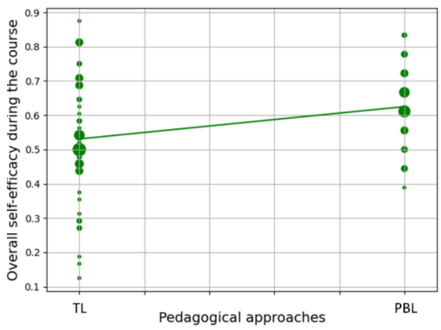

Fig. 2 Correlation between overall self-efficacy during the course and pedagogical approaches[2]

As seen from above, despite different levels of pre-course self-efficacy for TL and PBL, significant changes in students’ self-efficacy for both the approaches were found. More specifically, it can be seen that PBL results in less change in students’ self-efficacy than TL as seen in Fig 3 (Point-biserial r= -0.31, p= 0.02). This could simply be because the students in PBL had higher self-efficacy at the beginning of the course, which may be reflective of the PBL students’ programme more effectively increasing their self-efficacy. It could also be that TL is more effective in increasing student self-efficacy. It could be that the curricula the students had for their other courses might

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[1] Wilcoxon signed-rank test for non-parametric test for 2 related samples was used.

[2] The size of the points in the correlation plots show the number of individuals related to the corresponding horizonal and vertical axis values.

have followed the same transition (i.e., from TL→ to mainly PBL), which resulted in higher self-efficacy at their 5th year of study, hence, slight improvement in self-efficacy. However, this finding would be in opposition to previous research that typically recommends the use of PBL because it can increase student self-efficacy [e.g., 32].

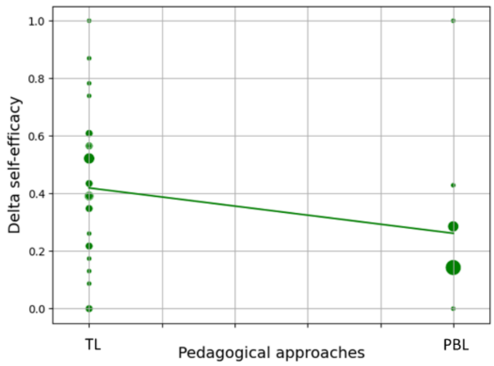

Fig. 3 Correlation between delta self-efficacy and pedagogical approaches

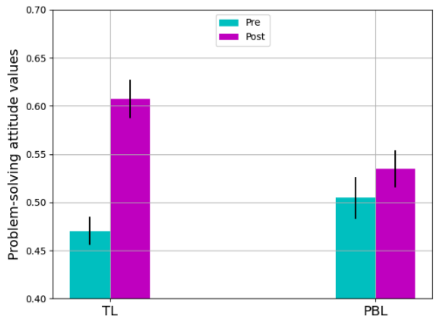

Fig. 4 Mean problem-solving attitude values for TL and PBL (normalized values)

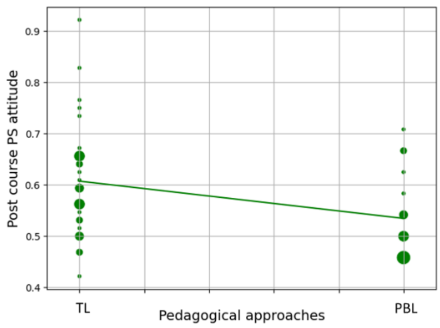

Fig. 5 Correlation between PS attitude at the end of the course and pedagogical approaches

Students' mean problem-solving attitudes at the beginning of the year were compared to the end of the year for each year for the part A and B surveys (Fig. 4). Similar to the mean self-efficacy (before and after) values for TL, problem-solving attitude (Fig. 4) also differed significantly ($W= 15.0$, $p< 0.001$) from the beginning to the end of the course. Additionally, TL students' problem-solving attitudes increased from the beginning ($M= 0.47$, $SD= 0.08$) to end ($M= 0.61$, $SD= 0.11$) of the course. However, PBL students' problem-solving attitude values at the beginning and end of the course did not differ significantly ($W= 38.5$, $p= 0.38$). Students' problem-solving attitudes at the end of the course were associated with the pedagogical approaches, where TL results in a higher increase in perceived problem-solving attitudes (Point-biserial $r= -0.4$, $p= 0.007$) as seen in Fig 5. This could be because unlike PBL, TL provides no hands-on experience of the design task and therefore students were over-confident in perceiving their problem-solving approach towards the end of the course. Another reason could be because TL proved better in improving students' problem-solving attitude towards the end of the course. Previous research found that a TRIZ-oriented course can improve students' problem-solving attitudes [6].

In order to get a more detailed understanding of the individuals' self-efficacy and problem-solving attitude, the response for each question for TL and PBL was compared. The difference comparison of the values entered by students at the beginning and end of the course for TL and PBL for each question can be seen in Fig. 6 (p-values[3]). It appears that most of the responses to the questions related to self-efficacy and problem-solving attitude for TL differed significantly from the beginning to the end of the course. The significant increase in self-efficacy within the TL course occurred during the following questions: (Q3) in the intimidation level of individuals, (Q5) their perceived success and (Q6) confidence when resolving a problem. The significant increase in students' problem-solving attitudes for the TL occurred for individuals' attitude towards (Q8) systems thinking, (Q9) implementing an algorithmic approach to PS, (Q10) the ideality of solutions, (Q11) the implications decomposition and partial solutions and (Q13) avoiding trade-offs and solving contradictions.

However, only a few questions had significantly different responses from the beginning to the end of the PBL course. PBL self-efficacy only increased for (Q6) students' confidence when resolving a problem from the beginning to end of the course. Additionally, PBL students' problem-solving attitudes increased from the beginning to the end of the course for (Q9) an algorithmic approach to PS, (Q13) avoiding trade-offs and solving contradictions and (Q14) the use of available resources to solve problems.

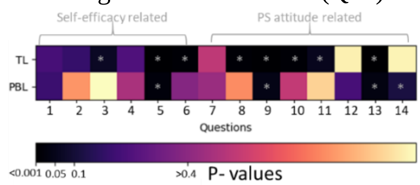

Fig. 6 Comparing the before with after values for the TL and PBL (* denotes significant increase, i.e., after values > before values)

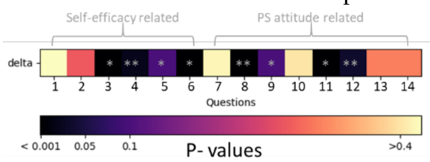

Fig. 7 Comparing the delta (after- before values) for the TL with the delta for the PBL (* denotes delta TL >delta PBL values while ** denotes delta PBL > delta TL)

The difference comparison of the delta values (after-before) for TL and PBL for all the questions in A and B (Table 1) can be seen in Fig. 7. The change in individuals' self-efficacy was greater for TL than PBL for questions that captured the (Q3) intimidation level of individuals and (Q6) confidence when resolving a problem. While the change in students' self-efficacy (Q4) for the ability to tackle unfamiliar tasks was more for PBL than TL. The (Q11) implications of problem decomposition and partial solutions was a significantly greater change for TL than PBL when looking at problem-solving attitude questions. While the change in individuals' attitude was significantly greater for PBL than TL towards (Q8) systems thinking and (Q12) their capability to abstract from the specific problem at hand.

[3] The p-values were obtained based on the parametric and non-parametric tests performed on the independent (delta PBL and delta TL) and related samples (before and after for PBL and TL)

3.2 The Effect of Instruction Modality

The mean EDSE values from the two PBL courses, the one held in-person (part C) and the one with a remote setting (part D), can be seen in Fig 8. The EDSE of the remote students before and after the course may be trending towards significant difference (W= 31.5, p= 0.097). When the course was held remotely, students' EDSE is trending towards being increased at the end of the course (M= 0.84, SD= 0.13) compared to the beginning (M= 0.80, SD= 0.15). However, in-person students' EDSE was not found to be significantly different (W= 66.5,.0, p= 0.6) from the beginning (M= 0.75, SD= 0.09) to end (M= 0.76, SD= 0.14) of the course. While previous research identified many aspects of an online course that make may impact students' self-efficacy [26], these results indicate that this course was successfully transitioned to a remote modality without consequences to students' self-efficacy.

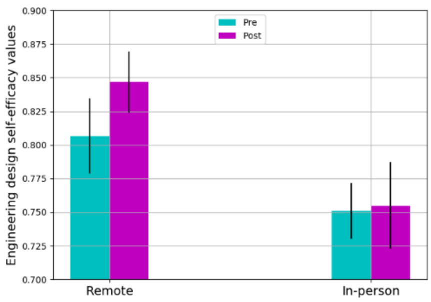

Fig. 8 Mean self-efficacy in remote and in-person mode (normalized values)

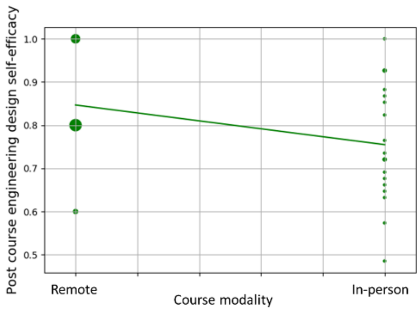

Fig.9 Correlation between post-course self-efficacy and teaching/collaborating modes

Despite the significant difference in the pre-course self-efficacy for the in-person and remote mode, students' self-efficacy at the end of the remote course was found to increase more than for the in-person course. This can be seen by the correlation found between the course modality and post-course self-efficacy (Point-biserial r= -0.33, p= 0.02) in Fig 9. These results indicate that remote instruction of a PBL TRIZ-oriented course may more successfully improve students' self-efficacy. One reason for the remote mode resulting in more self-efficacy at the end of the course could be due to an efficient collaboration environment [33] as students' familiarity with the digital technologies and the technologies mediating remote collaboration have been improved remarkably over the past few years.

Students' change in self-efficacy for the in-person and remote course was compared at the individual level to evaluate the two modes of instruction. The change in students' self-efficacy values (post-pre) in the two teaching modalities significantly differed (U= 2392.5, p< 0.001). When analysing the individual delta values for each student, it was found that the remote course was associated with a smaller change in students' self-efficacy compared to the in-person course modality (Point-biserial r= 0.34, p= 0.01) (Fig 10). This may be because in-person students had different team collaboration experiences than students in the remote course, which could have affected their change in

EDSE. As little or lack of physical interaction may have resulted in uniform peer influence [34], which might have caused less change in individuals' EDSE.

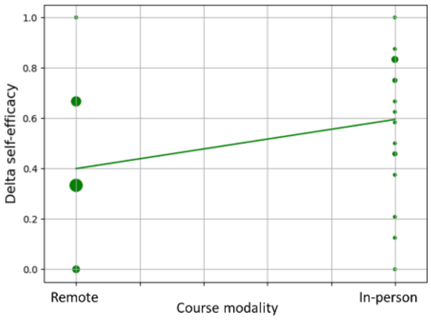

Fig.10 Correlation between change in individual self-efficacy during the course and teaching/collaborating modes

4 Conclusion

The study compared students' self-efficacy and problem-solving attitudes in the two pedagogical approaches of a TRIZ oriented course. It was found that PBL was more effective in improving student self-efficacy compared to the TL course. However, TL was more effective in improving problem-solving attitude at the end of the course. When comparing the PBL course modality at the end of the course, it was found that remote teaching and collaborating was more effective for increasing students' EDSE. Educators should promote hands-on training in their TRIZ courses.

When considering the implication of these results, it is also important to know their constraints. Data collection occurred over a span of years resulting in a relatively large interval between TL and PBL that likely caused a significant difference in the students' pre-course self-efficacy. This work did not randomize students to a condition but rather examined differences across years, which may have affected the results (e.g., pandemic-related changes). Moreover, the results were obtained using different survey formats for the remote and in-person data collection. This work should be replicated in the future with a smaller timeframe, more students, and more consistent survey formats.

These results should be leveraged to understand the strengths and weaknesses of the two pedagogical approaches and course modalities. Educators should strive to structure their courses to boost students' self-efficacy and problem-solving attitude.

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