Exploring Teaching and Learning TRIZ in Secondary STEM Education: A Systematic Review of Empirical Studies

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DOI: https://doi.org/10.47772/IJRISS.2025.91200069

Received: 10 December 2025; Accepted: 17 December 2025; Published: 31 December 2025

ABSTRACT

Theory of Inventive Problem Solving (TRIZ) is a powerful approach to fostering creativity, problem-solving, and innovation in science, technology, engineering and mathematics (STEM) education. However, its implementation in secondary STEM education remains underexplored. This study aims to systematically review empirical studies on the teaching and learning of TRIZ in secondary STEM education. The review follows the Preferred Reporting Items for Systematic Reviews and Meta-Analysis guidelines. Articles were sourced from Science Direct, Scopus, Springer, and ProQuest. The analysis identifies research trends, TRIZ tools and methods, pedagogical approaches, instructional strategies and measurable learning outcomes. TRIZ is more popular in Asia and Europe. The empirical studies are either mixed-method or quantitative. TRIZ is integrated into secondary STEM education through either enrichment or infusion approaches. Training varied from weeks to a year. Three TRIZ instructions methods and five TRIZ tools were identified, with contradiction analysis being the most popular tool. Project based learning and hands-on problem-solving are the most mentioned pedagogical methods and instructional strategies, respectively. TRIZ improved students' knowledge, technical skills and attitude.

Keywords: TRIZ, STEM education, secondary education, inventive problem solving, systematic review

INTRODUCTION

Theory of Inventive Problem Solving, widely known as TRIZ, has emerged as a powerful tool to foster creativity and systematic problem-solving skills across educational disciplines (Reyes-Huerta, Mitre-Hernandez, & Jaramillo-Avila, 2023) from kindergarten (Kizi, 2022; qizi Urinova, & Arzikulov, 2023), primary (Artikgul, 2024), lower secondary (Yachina, Gorev, & Nurgaliyeva, 2015), upper secondary (Chung, Dzan, & Lou, 2017) to higher education (Belski, Baglin, & Harlim, 2013; Cano-Moreno, Arenas Reina, Sánchez Martínez, & Cabanellas Becerra, 2022; Coello, Rodríguez, Banguera, & Baidal, 2024).

Initially developed by Genrich Altshuller to promote inventive solutions in engineering (Yeoh, Yeoh, & Song, 2009), TRIZ has since gained recognition in various educational contexts, including STEM education (Cavdar, Yıldırım, Kaya, & Akkus, 2024; Lou, Chung, Dzan, Tseng, & Shih, 2013a). STEM is critical in equipping students with the necessary skills to address real-world problems (Yeung, Yeung, Sun, & Looi, 2024). The growing importance of STEM education highlights the need for methodologies that impart technical knowledge and nurture creative and critical thinking (Ilma, Wilujeng, Widowati, Nurtanto, & Kholifah, 2023).

Secondary education is a crucial period where students begin to shape their cognitive skills, making it an ideal stage to introduce TRIZ methodologies (Zulhasni & Iqbal, 2020). Integrating TRIZ into STEM education, particularly at the secondary level, offers unique opportunities for students to engage in creative, structured problem-solving tasks, enhancing their ability to innovate, and approach challenges systematically through practical, hands-on activities with real-world applications (Cavdar et al., 2024; Lou et al., 2013a).

Despite the growing interest in TRIZ, the adaptation of its principles and tools to secondary education remains underexplored. This systematic review seeks to analyse the existing empirical studies on TRIZ within secondary STEM education from 2010 to 2024, focusing on the types of studies conducted, the tools and methods applied, pedagogical approaches, instructional strategies, and the learning outcomes achieved. By addressing these aspects, this review seeks to provide insights into how TRIZ contributes to secondary STEM education and informs future educational practices.

LITERATURE REVIEW

TRIZ was developed by Genrich Altshuller in 1946. After analysing 200,000 patents, he found that inventors often faced challenges in solving inventive problems, especially contradictions where improving one feature would compromise another (Gadd, 2011; Guin, Kudryavtsev, Boubentsov, & Seredinsky, 2009; Park, 2023). For instance, a small cabinet has limited storage capacity, but increasing the storage capacity will increase the weight. He compiles the recurring solutions into 40 inventive principles and offers a systematic framework to generate these innovative solutions (Cameron, 2010; Gadd, 2011; Yeoh et al., 2009).

Since 1946, many tools have been added to TRIZ. By 2020, there were at least 25 TRIZ tools (Ng, Ng, Ang, Wahab, & Mohamad, 2020). These tools are 9-Windows, ARIZ, inventive principles, benchmarking, cause and effect chain analysis (CECA) , clone problem application, engineering contradiction, failure anticipation analysis, feature transfer, flow analysis, function analysis, component analysis, function-oriented search, ideality/ideal final result, inverse analysis, patent strategies, perception mapping, physical contradiction, process analysis, process trimming, S-curve analysis, scientific effects, smart little people, substance-field analysis, super-effects analysis, trends of engineering system evolution. Ng et al. (2020) defined TRIZ tool as something that is used to perform an operation in the practice of a vocation or profession. On top of that, Reyes-Huerta et al. (2023) uncovered several TRIZ-derived methods that provide streamlined guidelines to enhance the usability and understanding of TRIZ. These include TRIZ-pedagogics (Lepeshev, Podlesnyi, Pogrebnaya, Kozlov, & Sidorkina,,2013), simplified TRIZ (Rantanen, 2002), Systematic Inventive Thinking (Boyd, 2013), new Engineering (Ge & Shi, 2019), TRIZ and design thinking (Da Silva, Kaminski, & Armellini, 2020).

TRIZ is known for its benefits in three areas namely knowledge, technical skills and teamwork. For knowledge and capabilities, TRIZ provides a systematic framework for identifying, clarifying, and solving problems, enhancing both the quality and quantity of solutions compared to traditional approaches (Ilevbare, Probert, & Phaal, 2013; Keong, Yip, Swee, Toh, & Tai, 2017; Kowaltowski, Bianchi, & de Paiva, 2010; MalAllah, Alshirawi, & Al-Jasim, 2022; Reyes-Huerta et al., 2023). It fosters innovation by enabling breakthrough solutions and the development of new concepts while supporting future-focused planning through its ability to anticipate technological evolution (Ilevbare et al., 2013). Moreover, TRIZ facilitates creative thinking strategies to increase creativity in product design and the successful implementation of novel ideas (Chang, Chien, Yu, Chu, & Chen, 2016; MalAllah et al., 2022). In terms of technical skills, TRIZ demonstrates the potential as an effective instructional method for fostering creativity in education which improves creativity and teaching self-efficacy in preservice teachers (Park, 2023). Finally, TRIZ enhances teamwork and collaboration by providing a shared problem-solving language that fosters cooperative efforts and aids in the deconstruction of patents for collective understanding (Ilevbare et al., 2013). Additionally, it boosts creative confidence and strengthens self-efficacy, empowering individuals to tackle future and unfamiliar problems with increased assurance and resilience (Harlim & Belski, 2015; Park, 2023; Sire, Haeffelé, & Dubois, 2015).

The above benefits have resulted in TRIZ gaining global adoption in various industries such as energy and electrical, home appliances, mechanical engineering, automotive, electronics, civil engineering, information and communication, healthcare, biomedicine, chemical, textiles, eco-design, human-computer interaction, conceptual design, science, automated guided vehicle and production process (Chechurin, 2016; Chen, Kamarudin & Yan, 2021; Fiorineschi, Frillici & Rotini, 2018; Ghane, Ang, Cavallucci, Kadir, Ng & Sorooshian, 2022; Zulhasni & Iqbal, 2024; Shqipe Buzuku, 2017; Sojka & Lepšík, 2020; Spreafico & Russo, 2016)

STEM education is crucial for equipping students with 21st-century skills necessary for the modern workforce (Thibaut, Ceuppens, De Loof, De Meester, Goovaerts, Struyf, Boeve-de Pauw, Dehaene, Deprez, & De Cock, 2018). It emphasizes analytical thinking, collaboration, and technological proficiency, which are essential in today's job market. The structural approach of TRIZ and its ability to foster creativity and problem solving has been identified as a valuable addition to STEM curricula (Alamian & Saedi, 2020; Alwana, 2020; Barak, 2013; Cavdar et al., 2024; Haeffelé, Dubois, & Sire, 2015; Kalimullin & Utemov, 2017; Lou et al., 2013a; Saygı & Şahin, 2023; Yıldırım & Yildirim, 2024; Zulhasni & Iqbal, 2020).

TRIZ can be taught by using either the enrichment or infusion approach. In the enrichment approach, TRIZ is taught in parallel with the existing domain-specific subject (Belski et al., 2013; Berdonosov, 2013; Busov, 2010; Yıldırım & Yildirim, 2024; Abdul Rahim Zulhasni & Iqbal, 2020). As for the infusion approach, TRIZ is infused in the syllabus of the subject (Lepeshev et al., 2013; Pogrebnaya et al., 2013; Yıldırım & Yildirim, 2024; Zulhasni & Iqbal, 2020). The duration of learning and teaching TRIZ varies from hours (Filmore, 2006), days Song, Youn, Ryu, & Kim, 2014; Wits, Vaneker, & Souchkov, 2010), months (Han & Yoo, 2014; Hellberg & Scheers, 2016; Lim, Khoo, & Tan, 2015) or years (Lu & Xue, 2017). Integrating TRIZ with STEM education enhances students' interest, motivation, and learning outcomes (Suhirman & Prayogi, 2023). Examples like designing a pneumatic propeller for ships (Lou et al., 2013a) highlight its positive impact on creativity and performance. In Malaysia, TRIZ was introduced into the 2018 secondary school Design and Technology syllabus for form two students, focusing on inventive problem-solving skills through tools like problem categorization, functional analysis, cause-effect chain analysis, and inventive principles, fostering creativity and critical thinking (Zulhasni & Iqbal, 2020).

Pedagogical approaches serve as overarching frameworks guiding the teaching and learning process (Yeung et al., 2024). Specific instructional strategy, such as hands-on activities, collaborative group work, and career exploration, is referred to the specific methods utilized within each approach to enhance their effectiveness (Kennedy & Odell, 2014). Suhirman & Prayogi (2023) proposed five steps to establish an effective pedagogy in STEM education. The first step is to create an innovative and engaging learning environment in the classroom to encourage inquiry, experimentation, and critical thinking. The second step is utilizing authentic learning methods and relevant learning resources to develop problem solving skills, metacognitive reasoning and motivation among students (Suhirman & Prayogi, 2023). Authentic learning methods include problem-based learning (PBL), project based learning (PjBL), and case-based learning (Suhirman & Prayogi, 2023). The learning resources include multimedia and simulations and real-world applications (Suhirman & Prayogi, 2023). Thirdly, teachers facilitate a collaborative learning environment when carry out STEM activities to mirror professional teamwork and improving communication, problem-solving, and cognitive performance (Lange, Costley, & Fanguy, 2021; Suhirman & Prayogi, 2023). Fourth, having an inclusive learning environment that values diverse perspectives and experiences, will positively impacts students' engagement and perceptions of STEM (Suhirman & Prayogi, 2023). Finally, teachers should continue to reflect and evaluate their teaching strategies to stay updated with the advancements in STEM education (Sahin & Top, 2015; Suhirman & Prayogi, 2023).

Currently, only Reyes-Huerta et al. (2023) have conducted a systematic literature review (SLR) on the teaching and learning of TRIZ in education. Their review focuses on higher education, leaving secondary education largely underexplored, particularly in the application of TRIZ within STEM education and with reference to empirical studies. There is limited clarity regarding which TRIZ tools are most effective or suitable for secondary students. Moreover, TRIZ can be overwhelming for the students, particularly when presented within condensed learning sessions (Keong et al., 2017), not to mention the secondary students, who are in the process of developing foundational skills. This has prompted recommendations to simplify TRIZ for beginners without compromising its effectiveness (Ilevbare et al., 2013; Reyes-Huerta et al., 2023). While simplifying TRIZ for beginners has been suggested, there is little research on how to maintains its core principles while making it accessible to novices (Ilevbare et al., 2013). Most existing studies focus on higher education or professional training, with limited attention given to implementing TRIZ in secondary education (Belski et al., 2013), particularly within interdisciplinary STEM curricula (Suhirman & Prayogi, 2023). Ilevbare et al., (2013), Park

(2023), and Reyes-Huerta et al. (2023) studies the application of TRIZ and its learning outcomes in professional or higher education settings. As such, little is known about the learning outcome the participants might obtain through the teaching and learning TRIZ in secondary STEM education. This SLR seeks to address these key gaps.

One of the main goal of the SLR is to explore the effective ways to integrate TRIZ into secondary education STEM curricula. This study also seeks to examine the most frequently use TRIZ tools and the TRIZ methods used by the trainer to introduce TRIZ to the participants. In addition, the pedagogical methods and teaching strategies used by the researchers were evaluated to determine their suitability for teaching TRIZ integrated with STEM activities. Furthermore, this study seeks to provide a better understanding of the learning outcomes achieved by the participants after the interventions. The findings will enable the development of more informed recommendations for educators and policymakers to optimize the teaching and learning of TRIZ in secondary STEM education.

Articles published from 2010 to the 2024 were selected for the SLR. The year 2010 was chosen as the starting point following the approach used by Reyes-Huerta et al. (2023). This SLR seeks to analyse the existing empirical studies on TRIZ within secondary STEM education. The research questions served as a guide for this review:

1. What are the trends in the empirical studies of teaching and learning TRIZ in secondary STEM education from 2010 to 2024?

2. What are the TRIZ tools and methods in teaching and learning TRIZ in secondary STEM education?

3. What pedagogical approach and instructional strategies are adopted in teaching and learning TRIZ in secondary STEM education?

4. What are the learning outcomes of teaching and learning TRIZ in secondary STEM education?

METHODOLOGY

The systematic review adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, a widely recognized framework designed to enhance the transparency, credibility, and reliability of systematic reviews (Moher, Shamseer, Clarke, Ghersi, Liberati, Petticrew, Shekelle, Stewart, & Group, 2015). To effectively visualize and address critical review concerns, a four-phase flow diagram which consists of identification, screening, eligibility assessment, and inclusion stage was employed and is presented in Figure 1. This diagram provided a clear and structured representation of the review process, systematically detailing the stages of the study. By mapping these phases, the diagram facilitated a transparent and replicable process, ensuring that all decisions regarding the inclusion or exclusion of studies were well-documented and justified.

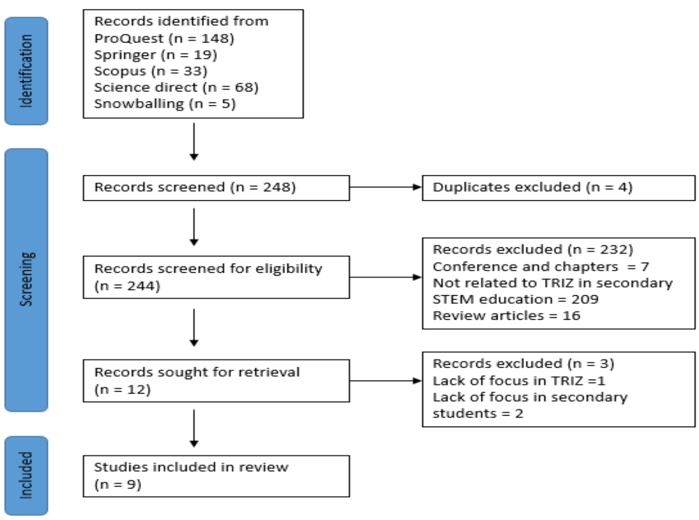

Figure 1: PRISMA Flow Chart Showing Article Screening Process

Identification

A comprehensive search was conducted through Science Direct, Scopus, Springer and ProQuest. These databases were known for their extensive repositories of academic articles and research studies (Gusenbauer & Haddaway, 2020). Additionally, these databases can be assessed through the authors' library system. Keywords such as "teaching," and "learning," were selected to gather diverse perspectives on pedagogy. "STEM" and "STEAM" were selected for the intended educational fields. "secondary education," "high school," and "middle school" were selected for the educational level of study. Based on these keywords, the Boolean query "(TRIZ) AND (STEM OR STEAM) AND (teaching OR learning) AND (secondary education OR high school OR vocational school)" was created to retrieve studies that aligned with the scope of the review. In addition to the keyword search, snowballing technique was applied by following the guidelines by Wohlin (2014)

Screening

After the articles were identification, some articles were removed due to duplication. These articles were further screened based on titles and abstracts. Further screening was carried out based on the inclusion criteria and exclusion criteria mentioned in Table 1.

Table 1: Inclusion and Exclusion Criteria

Criteria	Inclusion	Exclusion
Relevance	TRIZ in secondary STEM education	Outside the topic of TRIZ in secondary STEM education
Types of articles	Journals (research articles)	Conference papers, chapters in books, review articles
Language	English	Non-English
Timeline	From Jan 2010 until Dec 2024	Published before 2010

To ensure consistency with TRIZ in STEM education, a rigorous screening process was conducted on 273 entries, only 248 records were obtained after examining bibliometric information, including titles, abstracts, authors, and publication years. After that, 4 duplicate records were excluded, leaving 244 studies. Of these, 232 were excluded for being conference proceedings (7), review papers (16), or unrelated to TRIZ in secondary STEM education (209). The remaining 12 records underwent further screening, resulting in the exclusion of 3 papers due to a lack of focus on TRIZ (1) or secondary education (2). Ultimately, 9 full-text articles met the inclusion criteria for the review.

Analysis

A coding scheme was developed to systematically extract and analyse the data. To analyze the trends in teaching and learning TRIZ, the studies were systematically coded based on the country of origin, publication year, research methodology, targeted STEM disciplines, TRIZ approaches employed, and the duration of interventions. The TRIZ tools were coded based on the 25 tools identified by Ng et al. (2020). TRIZ methods were identified based on any simplified approaches streamlined the integration of TRIZ into the STEM education as described by Reyes-Huerta et al., (2023). The third research question focuses on examining the pedagogical approaches and instructional strategies employed in teaching and learning TRIZ within secondary STEM education contexts. The pedagogical approaches were analysed based on the frameworks that guide the teaching and learning process as described by Yeung et al. (2024). Whereas the instructional strategies were analysed for the specific techniques used within each pedagogical approach as described by (Yeung et al., 2024). Finally, the learning outcomes were coded and divided into three categories (knowledge, technical skills, and attitudes) following the methods used by Yeung et al. (2024).

Two researchers independently conducted the coding process and thoroughly reviewed the selected articles. Regular meetings were held to resolve discrepancies and achieve consensus. A structured, standardized approach ensured consistency in data extraction. A pilot test was conducted to refine the process. The high interrater reliability of 90.6% indicated a substantial level of agreement between the researchers (Belur, Tompson, Thornton & Simon, 2021).

RESULTS

Trends in the Empirical Studies of Teaching and Learning TRIZ in Secondary STEM Education

The reviewed research predominantly originates from Asia (Taiwan, Malaysia) and Europe (Russia, Turkey, and Israel), with three studies involving participants from Taiwan, two from Turkey, and one each from Malaysia, Russia, and Israel (refer to Table 2). The disciplinary focus varied, with three studies concentrating on science disciplines, two on technology, two integrating science and technology, and two exploring STEM approaches. Eight studies employed an enrichment approach, combining TRIZ with imaginative learning, STEM education, nanotechnology, and flipped learning through open-ended, project based tasks like designing vehicles or solving real-life problems, typically in short-term programs emphasizing creativity and innovation. In contrast, the infusion approach, used in one study, integrated TRIZ into a Malaysia curriculum for one year of study.

Research Methods

Cavdar et al. (2024) utilized a mixed-method approach to examine the effects of TRIZ-STEM activities in nanotechnology education on middle school students' skills and perceptions. A quasi-experimental design with a pretest-posttest control group model was implemented, involving 59 seventh-grade students divided into experimental (n = 30) and control (n = 29) groups. The experimental group participated in a four-week program integrating TRIZ-STEM activities, while the control group followed the standard curriculum. Quantitative data were collected through validated scales assessing critical thinking, problem-solving, and research inquiry skills. Additionally, qualitative data were gathered through semi-structured interviews with experimental group participants, exploring their perceptions of nanotechnology, the TRIZ-STEM activities, and engineering.

Yıldırım & Yildirim, (2024) conducted a mixed-method study to assess the impact of TRIZ-STEM applications within an online flipped learning model on teachers' problem-solving skills, creative thinking dispositions, STEM teaching practices, and understanding of engineering concepts. Using a quasi-experimental pretest-posttest control group design, 57 teachers were divided into an experimental group (n = 33), which participated in eight weeks of online flipped TRIZ-STEM activities, and a control group (n = 24), which received face-to-face TRIZ-STEM education. Quantitative data were collected through validated tools to measure changes in creative thinking, problem-solving skills, and perceptions of engineering concepts. Additionally, documentary analysis of lesson plans and activity logs provided qualitative insights into the integration of STEM principles, TRIZ application, and alignment of teaching practices with STEM objectives.

Saygı & Şahin (2023) conducted a mixed-method study to examine the effects of a systematic approach to real-life inventive problem-solving in a seventh-grade science classroom. The study employed a quasi-experimental pretest-posttest control group design involving 78 students. The experimental group received four weeks of systematic inventive problem-solving (SIPS) training, while the control group followed the standard curriculum. The participants' problem-solving skills were evaluated both prior to and following the intervention. For the qualitative analysis, structured interviews were conducted with the experimental group to explore their overall perceptions of inventive problem-solving and their experiences with the SIPS methodology.

Zulhasni & Iqbal (2020) surveyed 1,032 respondents for their understanding, application, and impact of TRIZ infused in the form two secondary schools' design and technology curriculum in Malaysia. The respondents were mostly teachers (n = 941) and secondary students (n = 72).

Chung et al. (2017) studied the impact of an eight-week TRIZ instructional strategy on 60 second-year vocational high school students' imaginative learning and practical skills. The study follows a quasi-experimental pretest-posttest design. Students were organized into 15 teams and applied TRIZ principles to design an "amphibious vehicle" project. The changes in their imaginative learning were tested before and after the project. Interviews were conducted with members of the top-performing teams to find out how the TRIZ principles, collaboration, and the instructions impact their creativity. Additionally, students' learning portfolios, design blueprints, project reports, and reflective notes, were analyzed to track their imaginative learning growth, problem-solving abilities, and practical use of TRIZ strategies when doing the project.

Kalimullin & Utemov (2017) studied the impact of an open-ended tasks on the creativity among 839 secondary school students from 71 educational institutions. The study employed a quasi-experimental design. Participants were divided into experimental group (n = 452) and a control group (n = 387). Students in the experimental group participated in two creativity-focused courses. Those in the control group followed the standard curriculum. The changes in their creative levels were assessed before and after the intervention based on the solutions originality, elaboration, and optimality. Classroom observations were carried out to gather data on student engagement, collaboration, and the use of heuristic methods. The learning dynamics and the challenges involved in fostering creativity were obtained from the document analysis of teachers’ notes and students’ reflections.

Barak (2013) conducted a longitudinal study to track the transition from systematic to heuristic problem-solving. The study used a quasi-experimental design. The 8^{th} grade students were divided into experimental group (n = 112) and control group (n = 100). Over 15 weeks, the experimental group was taught inventive problem-solving methods, while the control group followed the standard curriculum. A pre- and post-course quizzes were conducted to evaluate participants’ problem-solving abilities and their attitudes toward creativity. Participants’ portfolios, class assignments, and written solutions were analysed for the problem-solving application. Additionally, semi-structured interviews were conducted to study the perceptions of creativity and their reflections on the course. Observations were carried out using video recordings and anecdotal notes to study the classroom dynamics and the progression of problem-solving strategies.

Table 2: Major Trends in the Empirical Studies

Author(s)	Aim	Country	Respondent	STEM Discipline	Research Methods	TRIZ Approach (Duration)
Cavdar, Yıldırım, Kaya, & Akkus (2024)	To investigate the effect of TRIZ-STEM activities on middle school students' problem-solving, critical thinking, research inquiry skills, and views on nanotechnology and engineering.	Turkey	7^{th} grade Student	Science	Mixed method (experimental research + interview + survey)	Enrichment (4 weeks)
Yıldırım & Yildirim, (2024)	To examine the effects of TRIZ-STEM applications within an online flipped learning model on teachers’ problem-solving skills, creative thinking, and understanding of engineering and STEM teaching.	Turkey	Teachers (pre-school, primary, secondary)	Science, Technology, Engineering, Mathematic	Mixed method (Experimental + survey + documentary analysis)	Enrichment (8 weeks)
Saygı & Şahin (2023)	To explore how the SIPS approach can improve students' ability to solve real-life inventive problems in science, focusing on topics like light and energy.	Turkey	7^{th} grade Student	Science	Mixed method (experimental + interview)	Enrichment (4 weeks)

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume IX Issue XII December 2025

Zulhasni & Iqbal (2020)	To examine how TRIZ is adopted in Malaysia's education policy to enhance problem-solving skills within STEM education.	Malaysia	Secondary school teachers & students, engineer, entrepreneur	Technology	Quantitative (survey)	Infusion (1 year)
Chung et al. (2017)	To explore the effect of TRIZ instructional strategies on students' imaginative learning and practice, focusing on vocational students in Taiwan.	Taiwan	Vocational students	Science, technology	Mixed method (Experimental research + documentary analysis + interview)	Enrichment (8 weeks)

(Continue)

Author(s)	Aim	Country	Respondent	STEM Discipline	Research Methods	TRIZ Approach (Duration)
Kalimullin & Utemov (2017)	To explore the effectiveness of open type tasks for enhancing creativity in secondary school students, focusing on generating optimal, efficient, original, and well-elaborated solutions.	Russia	5th to 9th grade students	Science	Mixed method (Experimental research + documentary analysis + observation)	Enrichment (Not specified clearly)
Barak (2013)	To examine the effect of teaching inventive problem-solving principles on students' abilities to propose creative solutions and transition from systematic to heuristic problem-solving methods.	Israel	8th grade Students	Science, technology	Mixed-method (experimental research + documentary analysis + interviews, + observation)	Enrichment (15 weeks)
Lou et al. (2013a)	To explore the effects of TRIZ creative learning in building a pneumatic propeller ship while integrating STEM knowledge among female high school students in Taiwan.	Taiwan	High school students	Science, Technology, Engineering, Mathematic	Mixed method (Survey + Interview + documentary analysis	Enrichment (6 weeks)
Lou et al. (2013b)	To develop a feasible instructional model for blended TRIZ creative learning and verify its effectiveness in improving students' creativity and attitudes.	Taiwan	High school students	Technology	Mixed method (Experimental research + survey + documentary analysis)	Enrichment (18 weeks)

Lou et al. (2013a) conducted a mixed-method study to evaluate TRIZ creative learning integrated with STEM, involving 70 female high school students participating in a six-week program focused on designing and building a pneumatic propeller ship. Students worked in teams and engaged in activities applying TRIZ principles within a STEM framework. Quantitative data were collected through a 5-point Likert scale questionnaire to assess learning effectiveness, attitudes, and creative learning outcomes, providing insights into the instructional model's impact. Focus group interviews gathered qualitative data on students' learning processes, challenges, and perceptions of STEM knowledge application. Additionally, learning portfolios, including online platform records, group discussions, and project reports, were analyzed to track the development of students' creative and problem-solving skills, documenting the practical application of TRIZ principles and STEM knowledge throughout the project.

Lou, Chung, Shih, Tsai, & Tseng (2013b) evaluated a blended TRIZ creative learning model using a mixed-method approach. The study employed a quasi-experimental design with 56 female senior high school students divided into 14 groups. Over an 18-week intervention, students engaged in three phases: traditional classroom teaching, online learning, and project based activities. The model integrated inventive problem-solving strategies to enhance creative thinking and interdisciplinary application. Students completed TRIZ-based tasks in three stages, culminating in group presentations to assess learning outcomes. A validated 5-point Likert scale survey was administered post-intervention to measure learning effectiveness, attitudes, platform usage, and TRIZ creative learning. Additionally, students' learning portfolios, including activity logs, group discussions, assignments, and project reports, were analysed to evaluate the development of creative and problem-solving skills, the application of TRIZ principles, and the integration of STEM knowledge into practical tasks.

TRIZ Tools and Methods in Teaching and Learning TRIZ in Secondary STEM Education

TRIZ Tools

The distributions of TRIZ tools are shown in Figure 2. Yıldırım & Yildirim, (2024) did not mention any TRIZ tool, while the rest mentioned at least one TRIZ tool in their studies. In nanotechnology education, participants identified contradictions in daily challenges to develop innovative solutions contributing to engineering advancements and societal benefits (Cavdar et al., 2024). Kalimullin & Utemov (2017) emphasized the role of internal contradictions in open-type educational tasks, enabling students to engage deeply in learning. Chung et al. (2017) demonstrated the effective use of the TRIZ contradiction matrix and the 40 inventive principles in guiding students through the imaginative design of a multipurpose amphibious vehicle. Students applied inventive principles to address situational problems to overcome material limitations (e.g., batteries, motors, and vehicle modules), and create detailed design blueprints. In a blended learning case study by Lou et al. (2013b), students resolved a technical contradiction in boat manufacturing, where ease of production conflicted with strength. Using the TRIZ contradiction matrix, they identified engineering parameters and applied inventive principles such as separation, improvement of partial characteristics, and advanced action. This approach successfully balanced simplicity and structural integrity. Similarly, Lou et al. (2013a) reported using the contradiction matrix and inventive principles during the design of a pneumatic propeller ship. Over several weeks, students analysed contradictions, collaboratively resolved them, and synthesized findings to construct optimized designs. Barak (2013) highlighted the role of component and function analysis combined with five selected principles—duplicating, assigning new functions, eliminating components, changing relationships between variables, and dividing/separating components. Component analysis involves breaking a system into elements to understand their roles and functions. For example, in solving credit card delivery issues, component analysis identified key elements like customers, banks, ATMs, and shops, leading to inventive solutions such as eliminating the bank, assigning a new function to ATMs, and separating card functions from stored information. Saygı & Şahin (2023) conducted a problem-solving program where pupils first identified the Closed World (CW) of a problem, analysing system components before applying the Five Idea Thinking Tools (FITT): unification, multiplication, division, object removal, and breaking symmetry. Finally, Zulhasni & Iqbal (2020) outlined the application of TRIZ tools in the problem solving activity. The problem solving process begins with problem identification. The identified problem is further analysed using TRIZ tools such as functional analysis, component analysis and CECA. A problem model is created by physical contradiction before using the suitable inventive principles to generate solutions.

TRIZ Methods

Three methods were identified. Chung et al. (2017) highlighted an instructional model encompasses initiation, development, alternative, links and practice stages (IDEAL-P). In the initiation stage, participants were guided to build on their prior knowledge to stimulate their curiosity. In the development stage, students expanded their imaginative thinking from their original ideas to new ideas and developed their pre-planning abilities. During the alternative stage, students worked together to explore diverse perspectives of the problems. The 40 inventive principles were deployed in the first three stages. The links stage integrates multiple solutions into cohesive plans to foster systematic thinking. Finally, in practice stage, students' ideas were refined through iterative exploration and practical application. The 40 inventive principles and contradiction matrix were used iteratively during the links stage and the practice stage. As for the TRIZ-integrated instruction model by Lou et al. (2013a), it combines TRIZ innovative problem-solving with STEM education. This model organizes the TRIZ problem-solving process into three sequential stages: analysis of technological systems, description of technical contradictions, and solution of technical contradictions. Each stage is structured as a task, requiring students to apply STEM-integrated knowledge to identify and utilize corresponding inventive principles. The third TRIZ method, the SIPS framework is rooted in engineering, technology, and design to foster inventive problem-solving for classroom activities (Saygı & Şahin, 2023). The process begins with determining the CW of a problem, where students identify the components, elements, or resources already present within the problem or its immediate environment. Solutions are derived from these existing resources. Next, students apply the FITT, which includes unification, division, object removal, multiplication and breaking symmetry. Students use FITT either individually or in combination, depending on the problem and group characteristics, through iterative application of FITT, students learn to extract inventive solutions embedded within the problem by varying its components.

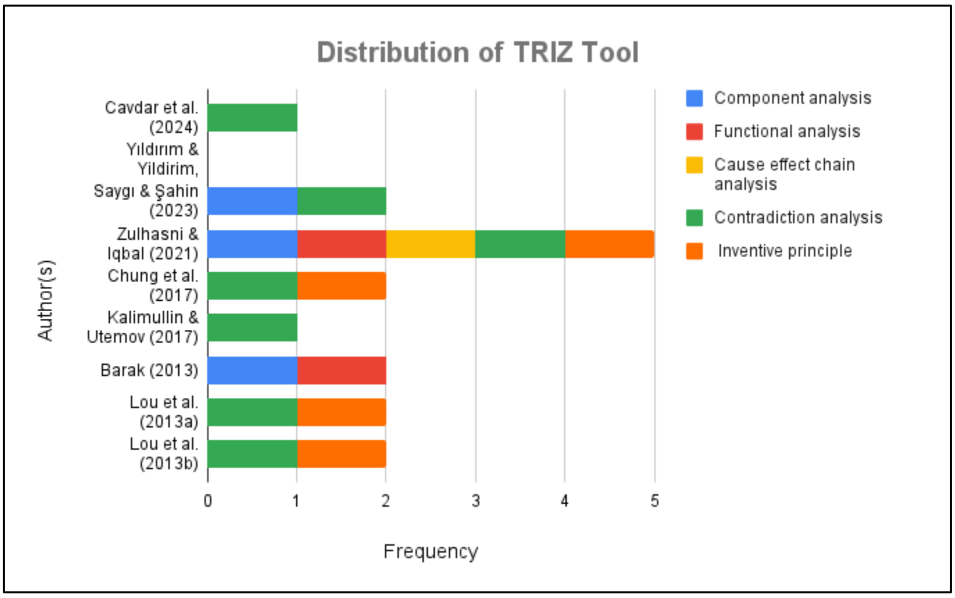

Figure 2: Distribution of TRIZ tools

Pedagogical Approach and Instructional Strategies Adopted in Teaching and Learning TRIZ in Secondary STEM Education

Several pedagogical approaches have been identified (refer to Figure 3), PjBL emerged as the most frequently reported approach (N = 4). This method engages students in tangible, goal-oriented tasks, such as designing engineering prototypes or participating in STEM competitions. For example, Barak (2013) described projects like designing amusement park models for individuals with disabilities and mechanisms to improve traffic safety. Similarly, Chung et al. (2017), Lou et al. (2013a) and Cavdar et al. (2024) integrated TRIZ principles with STEM education to guide students in constructing amphibious vehicles, pneumatic propeller ships and nanotechnology prototypes for humanity respectively. PBL, reported in three studies, challenges students with open-ended or inventive problems, requiring them to analyse, propose, and implement solutions. Kalimullin & Utemov (2017) highlighted the use of tasks like designing innovative circus performances or solutions to prevent ants from accessing food, encouraging divergent thinking. Zulhasni & Iqbal (2020) mentioned that TRIZ was used in the problem based learning for the secondary school design and technology syllabus. Saygı & Şahin (2023) utilised both inquiry based and problem based learning in their study of the effectiveness of SIPS on 7th grade students' problem-solving skills. Both Chung et al. (2017) and Lou et al. (2013b) mentioned blended learning in teaching TRIZ. For instance, Chung et al. (2017) described how students developed prototypes under the guidance of lectures and online resources. Lou et al. (2013b) integrated TRIZ instruction through a combination of traditional classroom teaching and web-based platforms to facilitate asynchronous collaboration and discussions among students. Inquiry based learning was reported by Barak, 2013 and Saygı & Şahin, 2023. Barak (2013) engaged students with challenging and open-ended tasks to encourage them to explore and asking critical questions. Saygı & Şahin (2023) highlighted the importance of active student participation in investigating design and technology concepts, promoting a deeper understanding through inquiry. Finally, Yıldırım & Yildirim (2024) utilized an online flipped learning model to deliver TRIZ-STEM education, allowing participants to access theoretical content through pre-class videos. In-class sessions were dedicated to practical exercises and group discussions, enabling participants to apply theoretical knowledge effectively.

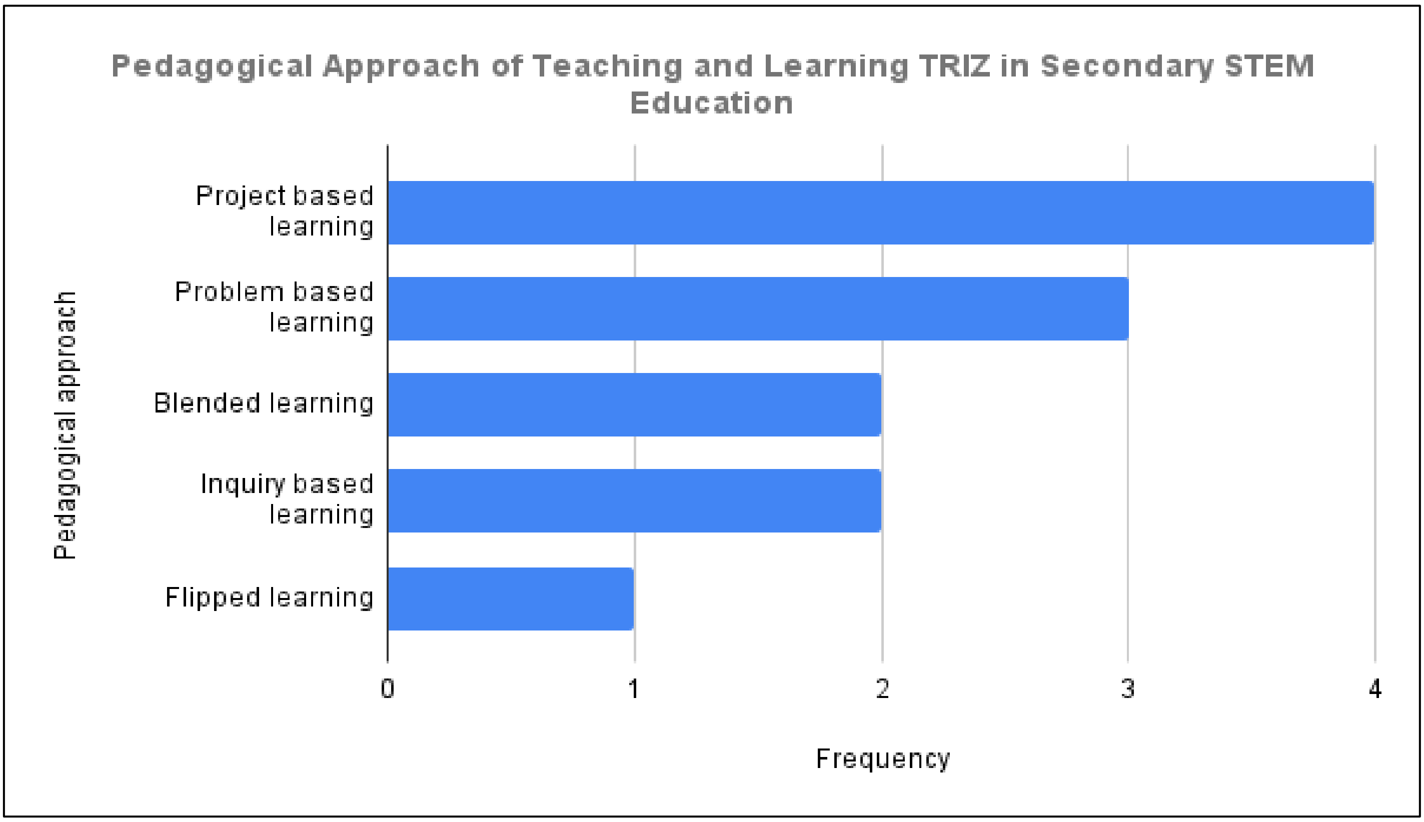

Figure 3: Pedagogical Approach

Instructional Strategies

As for the instructional strategies (Refer to Figure 4), hands-on activities were the most frequently utilized strategy (N = 5) which immerse students in practical tasks like building prototypes or conducting experiments. Barak (2013) guided students in constructing dual-level counters for wheelchair users and pedestrian safety bumpers, while Cavdar et al. (2024) focused on nanotechnology-related prototypes. Both Lou et al. (2013b) and Lou et al. (2013a) integrated TRIZ principles into hands-on projects like pneumatic propeller ships, allowing students to test and refine their designs. Collaborative learning (N = 4), fostered teamwork and group problem-solving. Barak (2013) involved students in small groups to design prototypes, while Chung et al. (2017) and Lou et al. (2013b) facilitated collaborative projects where students used both in-person and online platforms for brainstorming and innovation. Presentations (N = 4), enhanced communication skills, with students sharing findings and explaining inventive methodologies. For example, Saygı & Şahin (2023) showcased practical solutions like solar-powered devices. Homework and written assignments (N = 4), reinforced learning through reflection and practice. Barak (2013) required students to create detailed portfolios, while Kalimullin & Utemov (2017) assigned open-ended tasks to encourage creativity. Similarly, structured assignments in Lou et al. (2013b) and research-based tasks in Saygı & Şahin (2023) reinforced the application of TRIZ principles. Engineering design challenges (N = 2), strengthened real-world problem-solving skills. Chung et al. (2017) tasked students with designing amphibious vehicles addressing global warming and tourism, while Lou et al. (2013a) engaged students in creating pneumatic propeller ships. Demonstrations (N = 1), showcased prototypes to enhance application and presentation skills, as seen in Cavdar et al. (2024), Saygı & Şahin (2023), Lou et al. (2013a, 2013b). Competitions (N = 1) were highlighted by Lou et al. (2013a), where students presented and evaluated their designs in a final contest, fostering creativity and innovation. Lastly, lesson plan development, featured in Yıldırım & Yildirim (2024), integrated TRIZ into structured teaching plans within an online flipped learning model.

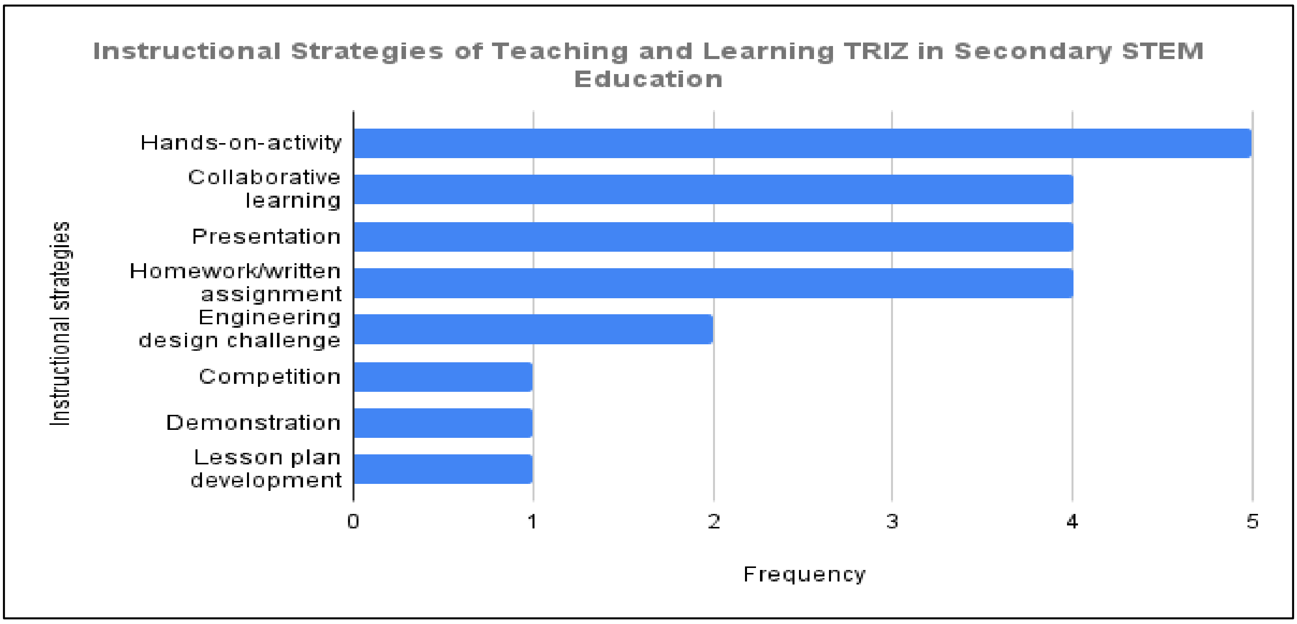

Figure 4: Instructional Strategies

Learning Outcomes of Teaching and Learning TRIZ in Secondary STEM Education

Knowledge

The most frequently reported gains in knowledge across the studies were enhanced problem-solving skills and creative learning, each cited in four studies (refer to Figure 5). Problem-solving is a central aspect of TRIZ that helps students transition from systematic to heuristic approaches, equipping them to address real-life STEM challenges systematically and creatively (Chung et al., 2017; Kalimullin & Utemov, 2017; Saygı & Şahin, 2023). TRIZ fosters creative learning by encouraging innovation and the development of novel solutions (Cavdar et al., 2024; Lou et al., 2013b). Imaginative learning and speed of knowledge learning are reported in one study. TRIZ aids students in thinking beyond conventional solutions (Chung et al., 2017) and enables students to comprehend and retain STEM concepts more efficiently (Lou et al., 2013b).

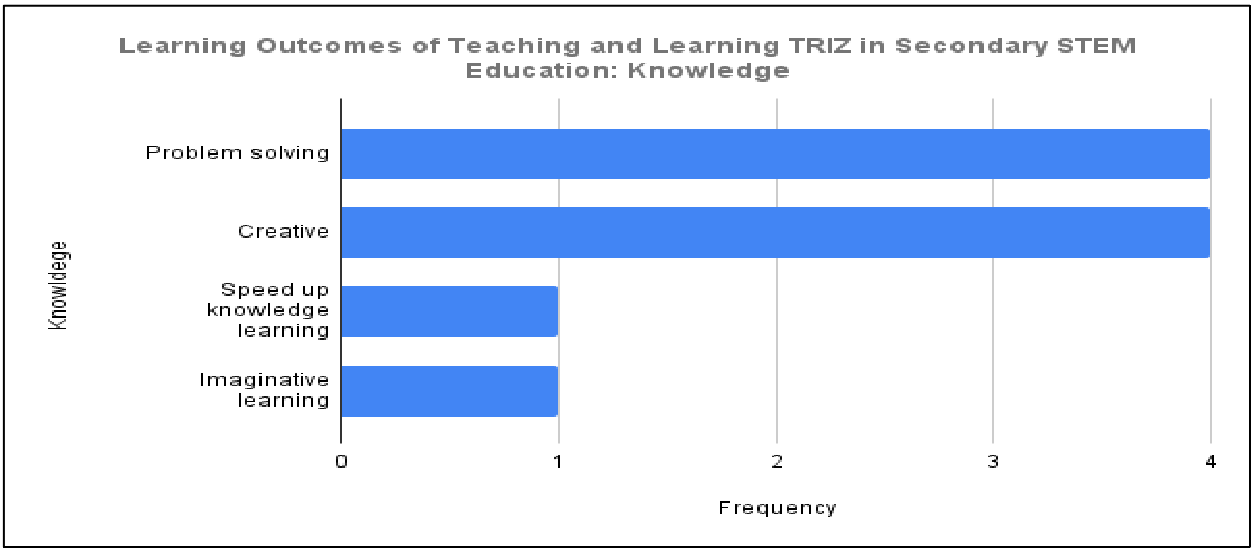

Figure 5: Knowledge

Technical Skills

The number of technical skills learning outcome is summarised in Figure 6. TRIZ significantly enhances students' technical skills by fostering knowledge application, demonstrating students' ability to apply theoretical concepts to real-world scenarios (Lou et al., 2013b; Saygı & Şahin, 2023). The enhancement in TRIZ application reflects students' growing mastery in utilizing TRIZ tools and techniques within practical projects (Lou et al., 2013b). Additionally, TRIZ supports the creation of original and useful solutions, showcasing students' capability to generate innovative and practical outcomes (Barak, 2013). Furthermore, improvement in STEM application reflects the successful integration of TRIZ principles into STEM activities, such as engineering projects, enhancing hands-on learning experiences (Lou et al., 2013a).

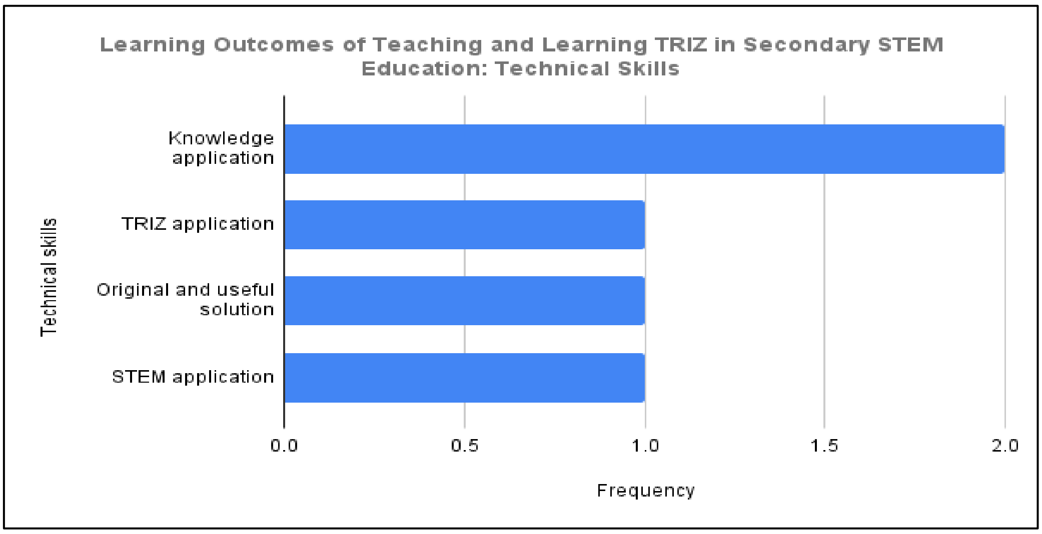

Figure 6: Technical Skills

Attitude

The frequency of the attitude learning outcome reported is shown in Figure 7. By integrating TRIZ into STEM education, students developed confidence in problem solving and creativity (Barak, 2013). Students are more proactive in collecting and analysing information (Lou et al., 2013b). It also boosts students' interest in TRIZ (Zulhasni & Iqbal 2020), STEM (Lou et al. 2013a), science (Saygı & Şahin, 2023), nanotechnology and engineering (Cavdar et al., 2024). TRIZ also improved students' confidence in problem-solving, enabling them to tackle complex challenges, and build self-assurance in creativity.

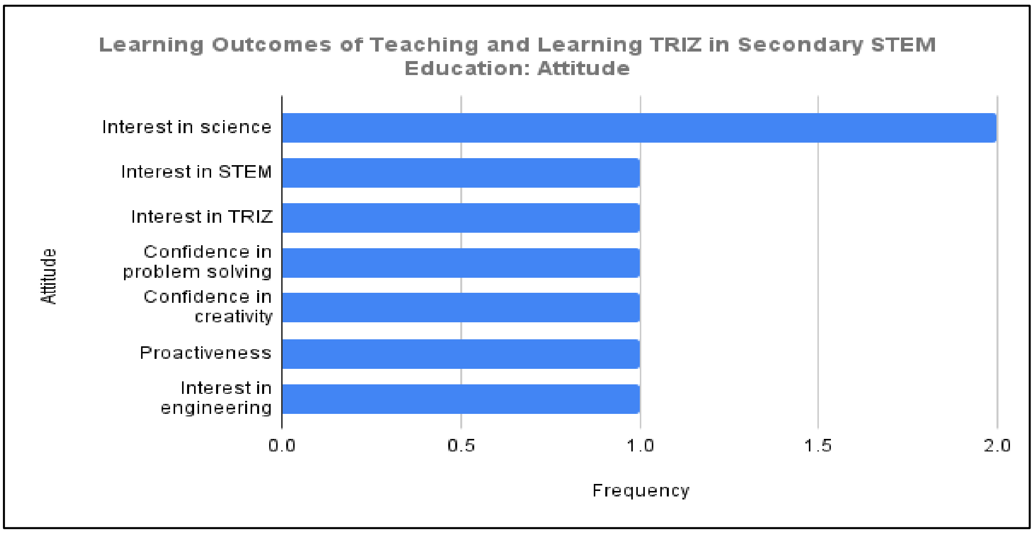

Figure 7: Attitude

DISCUSSION

Nine empirical studies were published between 2010 and 2024. These studies were from Asia (N = 4) and Europe (N = 5). Based on the limited number of empirical studies, it seems that the TRIZ teaching and learning in secondary STEM education may not yet be fully explored by researchers and educators. The reason could be due to TRIZ origins as a specialized methodology for engineering and industrial problem-solving which is rather complex (Yeoh et al., 2009). The complexity of TRIZ can be overwhelming for beginners including teachers and students (Ilevbare et al., 2013; Keong et al., 2017). This underscores the need for carefully designed teaching strategies to make TRIZ more accessible and effective for secondary students. TRIZ can be adapted to both specialized and interdisciplinary STEM as reported by Lou et al. (2013a) and Saygı & Şahin (2023). This versatility makes TRIZ a valuable methodology for secondary STEM education. Most studies (N = 8) reported teaching TRIZ parallel with the existing STEM subjects (enrichment approach). Enrichment TRIZ training lasted between 4 and 18 weeks, typically within a semester. On the other hand, the infusion TRIZ training as reported by Zulhasni & Iqbal (2020), takes at least a year and required the modification to the existing syllabus. It seems that, the enrichment approach offers reduced demand for additional time and resources compare to the infusion approach. Most studies conducted are predominantly mixed-method research designs (N = 8) with quasi experimental design (N = 7). Interviews, surveys, and documentary analysis are mainly deployed in qualitative ways of collecting data. These approaches provides a holistic evaluation of TRIZ-based instructional strategies and their impact on learning outcomes.

As for the TRIZ tools in teaching and learning TRIZ in secondary STEM education, contradiction analysis (including physical contradiction) emerges as the most frequently used tools (N = 7). It plays a critical role in fostering systematic problem-solving by identifying and resolving conflicts within systems. Similarly, the inventive principles supported innovative solution generation, guiding students in brainstorming creative ideas. Alternative principles, such as unification, division, object removal, multiplication, and breaking symmetry (Saygı & Şahin, 2023), along with duplicating, assigning, eliminating, and changing relationships (Barak 2013), were adapted from the original 40 inventive principles of TRIZ. These adaptations aim to make TRIZ more accessible, particularly for students with limited knowledge of physics or mathematics. However, these adaptations may compromise some of the original rigor and effectiveness, underscoring the need to balance simplification with preserving the depth that makes TRIZ a powerful tool for systematic innovation and problem-solving. Component analysis and functional analysis were utilized to help students understand the system and envision optimal solutions, while cause-effect chain analysis is the least reported tool. It traces the root causes of engineering challenges. Additionally, TRIZ-integrated instructional methods like IDEAL, SIPS, and TRIZ-integrated instruction model enhanced students' creativity, problem-solving skills, and engagement. Despite these successes, the limited application of some tools such as functional analysis and cause-effect chain analysis suggests opportunities for further exploration and broader implementation. The review also identifies some limitations. TRIZ teaching through flipped TRIZ-STEM by Yıldırım & Yildirim (2024) lacked detailed procedural descriptions, hindering replicability and deeper insights.

The findings underscore the importance of combining pedagogical approaches with instructional strategies to maximize learning outcomes of teaching TRIZ in secondary STEM education. PjBL is the most frequently reported pedagogical approach (N = 4). PjBL engages students in designing engineering prototypes which promote creativity and practical application (Barak, 2013; Cavdar et al., 2024; Chung et al., 2017; Lou et al., 2013a). PBL which requires students to solve open-ended problems is another prominent pedagogical approach mentioned by Kalimullin & Utemov (2017), Saygı & Şahin (2023) & Abdul Rahim Zulhasni & Iqbal (2020). As mentioned earlier by Suhirman & Prayogi (2023), both PjBL and PBL are able to develop problem-solving skills. On top of that, these methods also develop creativity (Barak, 2013; Cavdar et al., 2024; Kalimullin & Utemov, 2017; Lou et al., 2013a), interest in STEM related subjects (Cavdar et al., 2024; Lou et al., 2013a; Saygı & Şahin, 2023) and interest in TRIZ (Zulhasni & Iqbal, 2020) among students. A few articles highlight combination of two pedagogical approaches. Chung et al. (2017) combined blended learning with project based learning where the traditional instruction is combined with digital tools to teach application of TRIZ-STEM in constructing prototype. Saygı & Şahin (2023) performed problem based learning together with inquiry based learning. Barak (2013) on the other hand, reported inquiry learning combined with project based learning. (Suhirman & Prayogi, 2023) said that inquiry based learning creates an engaging learning environment to enhance students' critical thinking and self-directed learning. Among instructional strategies, hands-on activities are the most utilized (N = 5). This strategy is associated with PjBL and blended learning (Barak, 2013; Cavdar et al., 2024; Chung et al., 2017; Lou et al., 2013a, 2013b). Collaborative learning, presentations, and written assignments promote teamwork, communication, and reflective practice (Chung et al., 2017; Lou et al., 2013b; Saygı & Şahin, 2023).

Engineering design challenges and competitions encourage creativity and real-world problem-solving, while demonstrations enhance practical application and presentation skills (Lou et al., 2013a). Lesson plan development, incorporating TRIZ-STEM strategies, adds structure and coherence to teaching practices (Yıldırım & Yildirim, 2024). The study also explored students' attitudes and motivation, emphasizing their positive outlook toward STEM (Cavdar et al., 2024; S. Lou et al., 2013a; Saygı & Şahin, 2023; Zulhasni & Iqbal, 2020), increased confidence in problem-solving and creativity (Barak, 2013), and the development of a proactive mindset (Lou et al., 2013b) that fosters innovation and embraces challenges in STEM learning. These learning outcomes are similar to the learning outcomes obtained by adult from learning TRIZ as reported by Harlim & Belski (2015) & Ilevbare et al. (2013).

RECOMMENDATION

Scaling TRIZ requires moving beyond one-off workshops toward curriculum integration. Driven by national policy to transform national problem-solving capabilities, Malaysia has made TRIZ a mandatory component of the 'Design and Technology' syllabus in Form 2 secondary schools (Zulhasni & Iqbal, 2020). The infusion approach requires syllabus restructuring. The result, however, is a unique 'innovation literacy' where every student understands how to resolve technical contradictions using structured inventive principles (Zulhasni & Iqbal, 2020). While Malaysia takes a national approach, other countries use TRIZ for specific goals, such as bridging technical gaps in Taiwan (Chung et al., 2017; Lou et al., 2013a; Lou et al., 2013b), overcoming rote learning in Israel (Barak, 2013), learning to think creatively in Russia (Kalimullin & Utemov, 2017), or teaching nanotechnology in Turkey (Cavdar et al., 2024). The primary weakness of these models is that they are expert-dependent. There is a risk that the program won't be able to continue if the experts leave. For institutions to successfully integrate TRIZ using an enrichment or infusion strategy, they must invest in robust teacher training programs. This shifts the methodology from being expert-dependent to being an institutionalised part of the STEM syllabus.

TRIZ can be simplified for novices without compromising its core principles to enhance accessibility for secondary students. However, the simplification should maintain the TRIZ fundamental rule: resolve the contradiction rather than compromising. The first strategy is through focusing on high-impact tools such as physical contradiction analysis and specific inventive principles rather than utilizing the exhaustive 39x39 contradiction matrix and all 40 inventive principles (Barak, 2013; Zulhasni & Iqbal, 2020). The second strategy is to condense complex TRIZ into a manageable three steps model: analysing the technological system, defining the technical contradiction, and identifying the solution. This method can be seen in Chung et al (2017) and Lou et al., (2013b). This approach provides immediate utility by focusing on contradiction analysis within a "Closed World" framework, which restricts solutions to elements already present in the system. By limiting the search to the immediate context, this model reduces complexity and makes the inventive process significantly more manageable for secondary students.

Integrating TRIZ into PjBL or PBL frameworks ensures real-world relevance by grounding abstract principles in local cultural experiences, such as traditional festivals (Lou et al., 2013a). Students can foster practical learning by applying TRIZ tools alongside their STEM knowledge to solve everyday problems through hands-on applications, such as designing amphibious vehicles (Chung et al., 2017) or conducting microscale experiments such as nanotechnology (Cavdar et al., 2024). This will encourage teamwork, as students collaborate in small groups to tackle contradictions while developing essential communication and collaboration skills. Furthermore, incorporating presentations allows students to showcase their projects, demonstrate their mastery of STEM concepts, and build confidence in expressing their inventive ideas. Finally, future research should prioritize longitudinal studies to evaluate the sustained impact of TRIZ-STEM across diverse learning outcomes.

Limitation

Several limitations should be acknowledged to guide future research. The current SLR only include the English language academic publication. As a result, some information from the non-English language publication might omitted. Additionally, the reliance on specific databases that omit conference proceedings and books may have overlooked other significant contributions to the field. Seven studies relied on quasi-experimental designs without control groups and three studies are without comparative analyses, making them challenging to isolate the effects of TRIZ interventions from other factors such as teaching styles or curriculum variations. The short duration of TRIZ, lasting only a few weeks or a semester (Barak, 2013; Cavdar et al., 2024; Chung et al., 2017; Lou et al., 2013a, 2013b)., might limit the ability to assess long-term outcomes and the sustainability of benefits. Another notable limitation is the lack of standardized assessment tools for measuring the learning outcomes such as creativity and problem-solving. This results in context-dependent interpretations that reduce the reliability and comparability of findings. Inconsistent documentation of pedagogical strategies also makes it difficult to replicate or scale successful. Studies conducted in different countries may reflect unique cultural or educational contexts, which can limit the generalizability of their findings. Moreover, subjective evaluations based on documentary analysis, interviews, and observations may introduce potential biases. Finally, simplifying TRIZ principles to just a few by Barak (2013) and Saygı & Şahin (2023) compare to its original 40 inventive principles as mentioned by Ng et al. (2020), might reduce impact of TRIZ interventions.

CONCLUSION

In conclusion, this SLR highlights the various TRIZ tools, TRIZ methods, pedagogical approaches, instructional strategies, and learning outcomes associated with teaching and learning TRIZ in secondary STEM education. TRIZ can be integrated into secondary STEM education using either enrichment or infusion approaches. The training period for enrichment approach is shorter than the infusion approach. TRIZ tools reported in the empirical studies include component analysis, CECA, functional analysis, contradiction analysis and inventive principles with contradiction analysis being the most mentioned. IDEAL-P, TRIZ-integrated instruction model, and SIPS are the simple guidelines for the secondary school students to apply TRIZ together with STEM. The findings indicate that teaching TRIZ with combination of pedagogical approaches with instructional strategies can enhance students' knowledge, technical skills and attitude. However, certain limitations persist, including small sample sizes, short intervention durations, and inconsistent assessment methods. These challenges emphasize the need for more robust and standardized research approaches. Future studies should prioritize longitudinal research, larger and more diverse sample groups, and detailed documentation of teaching practices to ensure the validity and scalability of TRIZ-STEM integration.

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