The Adoption of the Theory of Inventive Problem Solving (TRIZ) in The Malaysia Education Policy and Curriculum for STEM Subject

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Abstract

The STEM body of knowledge has become a core focus for the Ministry of Education of Malaysia to be embedded in the mainstream education curriculum but one of the challenges is to improve the level of student competency in problem-solving skills. A new policy has been developed at the governmental level to ensure the change can be successfully made and executed successfully at the school level. One of the initiatives is to enhance the complex problem-solving skills of the students by introducing the Theory of Inventive Problem Solving (TRIZ) topic in the Curriculum and Assessment Standard Document for Design and technology subject. The integration of the TRIZ is streamlined with other creativity theories and thinking models. The adoption of TRIZ is strategically designed to support and complement the student in developing a technological project and design competencies. The teaching and learning process of TRIZ in the subject has started in 2018 as the first official textbook has been used in all schools around Malaysia. A survey has been carried out to 1032 respondents that involved in the process of teaching and learning the TRIZ topic in the subject. The result has shown positive feedback from respondents, and further issues have been highlighted to improve the process of teaching and learning in school.

Keywords: TRIZ, education policy, STEM, curriculum assessment standard.

Introduction

The 2017 High School Standard Program replaces the integrated Secondary School Curriculum, which was established in 1989. The secondary school standard curricula were designed to comply with the new policy criteria under the Malaysian Education Development Plan 2013-2025, which aims to enhance the quality of secondary school curricula by benchmarking according to international standards (Ministry of Education, 2013) . The international standards-based curriculum has been incorporated into the Secondary School Standard Curriculum through the drafting of the Curriculum and Assessment Standard Document (CASD) for all subjects containing content standards, learning standards and assessment standards (Curriculum Development Section, 2013).

Ever since the National curriculums are applied in the sense of the National Education System (NES) attempts to integrate the evaluation standard into curriculum documents have changed history. Continuing students can be assessed on an ongoing basis to identify their level of mastery in a particular subject, as well as enabling teachers to take follow-up actions to improve student achievement (Arshad et al., 2017).

The architecture for the Secondary School Standard curriculum blends awareness, abilities, beliefs and incorporates 21st-century skills and high-level thinking skills (HLTS) (Chun & Abdullah, 2019). The integration is intended to produce people who are intellectually and spiritually balanced, emotionally and physically as the National Education Philosophy demands. To be successful in implementing Secondary School Standard Curriculum, teachers' teaching and learning should emphasize the Inquiry-based Learning and Project-based Learning approaches, so that students can master the skills needed in the 21st century Jamaluddin et al., 2019).

Design and technology subject skills

The exposure to the subject of design and technology is fresh to the teachers and students from level 1 to level 3 in the high school curriculum. The topic of design and technology replaces the integrated subject of life skills that were introduced in 1988. In line with the desire to produce a thinking skill through the Malaysian Education Development Plan 2013–2025, then Design and Technology subject was introduced (Rusdin, 2018). Design and Technology subjects are taught to students about design criteria related to technology, developing products with global thinking and understanding the latest technology that solves complex problems.

The overarching vision of the topic of design and technology is to include design knowledge, skills, principles, aesthetics and technology. Pupils develop communication skills and generate ideas for new products and become designers who cultivate critical, creative, innovative, inventive and entrepreneurial thinking. It focuses on four domains, as shown in Figure 1. Pupils will apply their knowledge and skills through product design and production activities (Curriculum Development Section, 2013).

Design Appreciation

- Respect and appreciate the design around it for the purpose of improving the design or creating a new, cheaper and more efficient design.

Application Technology

- Learn and apply technology in design covering a wide range of disciplines.

Product Creation

- More efficient design and product development that involves the design process.

Product Design Evaluation

- Emphasize the moral values of learning to ensure products can solve individual and community problems while being competitive.

Figure 1. The Secondary School Standard Curriculum Domains

The subject of design and technology enables students to combine design and technological skills by creatively thinking and creating products that fulfil human needs (Masingan, & Sharif, 2019). Pupils are expected to develop a range of skills in line with the modern industry. Pupils learn to apply the latest technology and be aware of the impact caused by technological change. Students are also creative by participating in improving the quality of life and solve problems as individuals and expert communities. In the 21st century, students are not only acting as a user of technology but also as the creator of new products (Scheer et al., 2012).

School evaluation forms part of an evaluation approach, a mechanism for obtaining anticipated, implemented and recorded information on student progress by the particular instructor. This process takes place both formally and informally so that the teacher can determine the student's actual level of mastery. School assessments need to be conducted holistically based on inclusive, authentic and localized principles. Information gathered from teaching and learning will be used by administrators, teachers, parents and students in planning follow-up actions to improve student learning development. The same assessment is used in chapter one, TRIZ topic in the form 2 syllabus of Design and Technology subject.

Teachers should formulate and summarize school tests. Formative evaluation is conducted with the educative and learning method and a summative evaluation at the end of a study unit, term, semester and year (Hattie, & Brown, 2007). In conducting School Assessments, teachers must plan, construct items, administer, inspect, record and report on student's level of mastery in the subjects taught under the Curriculum and Assessment Standard Documents (Curriculum Development Section, 2013).

The purpose of the Design and Technology outcomes are to;

1. Inculcate student's awareness regards to cultural, environmental, and design issues.
2. Know the technology in design to solve a problem
3. Apply technology to systematically solve design problems.
4. Ability to produce products that have aesthetic, creative, ergonomic and commercial value.
5. Ability to present and present products with systematic documentation.

Performance Standard is a teacher's reference scale to determine student achievement in mastering content standards and learning standards. Performance standards are based on sections that demonstrate the level of mastery of students through the teaching and learning process (Yudkowsky, et al., 2015). Sections are built to measure achievement levels based on cognitive, psychomotor and affective domains. Achievement Standard consists of six hierarchical levels hierarchically organized from Mastery Level 1 that show the lowest achievement to the highest achievement, Mastery Level 6 (Curriculum Development Section, 2013). Each level of the Design and Technology subject mastery is generically defined as reflecting holistic student achievement, as shown in Figure. 2.

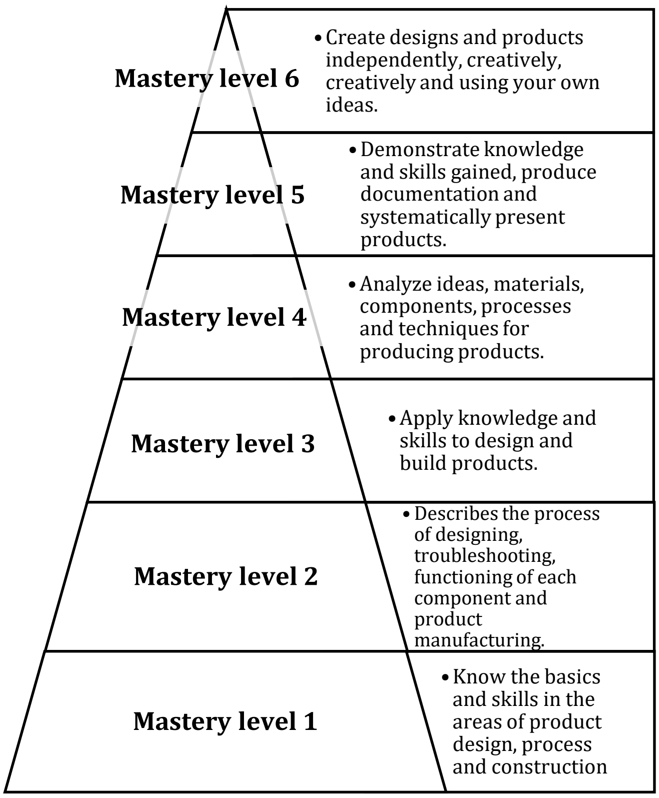


Figure 2. General Interpretation of Design and Technology Mastery Levels

The Introduction of TRIZ for STEM Education

In the 1940s, TRIZ began in the USSR. Genrich Altshuller, the Patent expert in the Soviet Navy Caspian Flotilla Inspection Department, has developed TRIZ. TRIZ came from the Soviet Union after World War II, with the main objective to accelerate industrial and technology development. Specifically, it was focused to boost the advancement of defence technologies.

However, due to limited resources, such as skilled and qualified engineers, it pushed them to find a faster method to learn and execute the development process. The best and quickest approach is through patent review. This is the most important source of the TRIZ theory. Through patent review analysis, it helped Genrich Altshuller identify patterns and trends of technology transition alongside technology development. He saw that the developments are centralized by the ability to resolve contradictions (Ekmekci & Nebati, 2019).

Genrich Altshuller and his students have also conducted detailed inquiries into the history of constructing the technological structure. The result showed that there was repeated patterns or stages of evolution that happened to all types of systems. This finding supported that other systems assumed to follow similar stages of evolution in their development. Therefore, this enhances the ability to forecast an evolving system that may follow a direction of probable generic trends (Ge & Shi, 2019). This development is not only guided by the trends and to support the theory, but it also becomes a self-verification within the evolution process (Ge & Shi, 2019).

By reflecting on the patterns in the pursuit of great potential ideas to solve inconsistencies, the psychology of the traditional thought process shifts (Zhang et al., 2019). The TRIZ theory helps to overcome the "psychological inertia" in finding inventive solutions (Khadija et al., 2019; Domkin et al., 2019) The problem is modelled into an inventive problem statement, which highlights the contradictions that need to focus and solved. The TRIZ methodology provides opportunities to discover new knowledge and technology that enhance the resources of engineers. Furthermore, this approach brings up rapid growth in the development of science and technology (Karnjanasomwong & Thawesaengskulthai, 2019).

In Table 1, inside the classical theory of TRIZ, Altshuller has made three statements (Altshuller, 1999). TRIZ has established its methods and techniques to explain the process of exploring solutions. The theory shows concepts and mechanisms to use laws of Technical System evolution and apply them through inventive problem-solving. This includes the approaches, methods, techniques, and guidelines in the application activities.

Table 1. Claims of Theory of inventive problem solving

TRIZ postulates	The first is that problems and solutions are repeated across industries and sciences,
	The second is patterns of technical evolution are also repeated across industries and sciences, and
	The third is that the innovations used scientific effects outside the field in which they were developed. In the application of TRIZ all these findings applied to create and to improve products, services, and systems

The ability and usefulness of the TRIZ approach are best adapted for STEM knowledge and applications in technical and technical terms (Vladimirovich et al., 2017). Several findings on the integration model between STEM and TRIZ have shown positive influences on the students' learning program (Belski, 2019; Chung et al., 2017). This research also shows how the integrated model of STEM and TRIZ enhance students' performance in learning attitude and level of interests. Furthermore, the greater outcome of the research explained how the integrated model able to develop positive influences on the creativity performance from the learning program. Figure 3 shows the integration model proposed in the study done with 70 high school students that focuses on building a pneumatic propeller for ships (Lou et al., 2017).

In this research, STEM courses were chosen because they were able to develop challenges, innovation and decision-making skills (Lou et al., 2017). This multiple skill is critical in naturing technology competencies for a future generation (Attiyah, 2018). Various literature provides such support on the related skills use in engineering problem solving that already available for focus on a problem-solving framework such as problem definition, root cause analysis, ideation, prototype, and test the solutions (Wells, 2016; Casner et al., 2018; Henriksen et al., 2017). However, there is literature that presents a particular thinking methodology such as TRIZ for problem-solving, which emphasized the mechanism of exploring creativity and innovation strategy in a more structured and systematic nature (Lui et al., 2020; Guner and Illker, 2020; Lee et al., 2020).

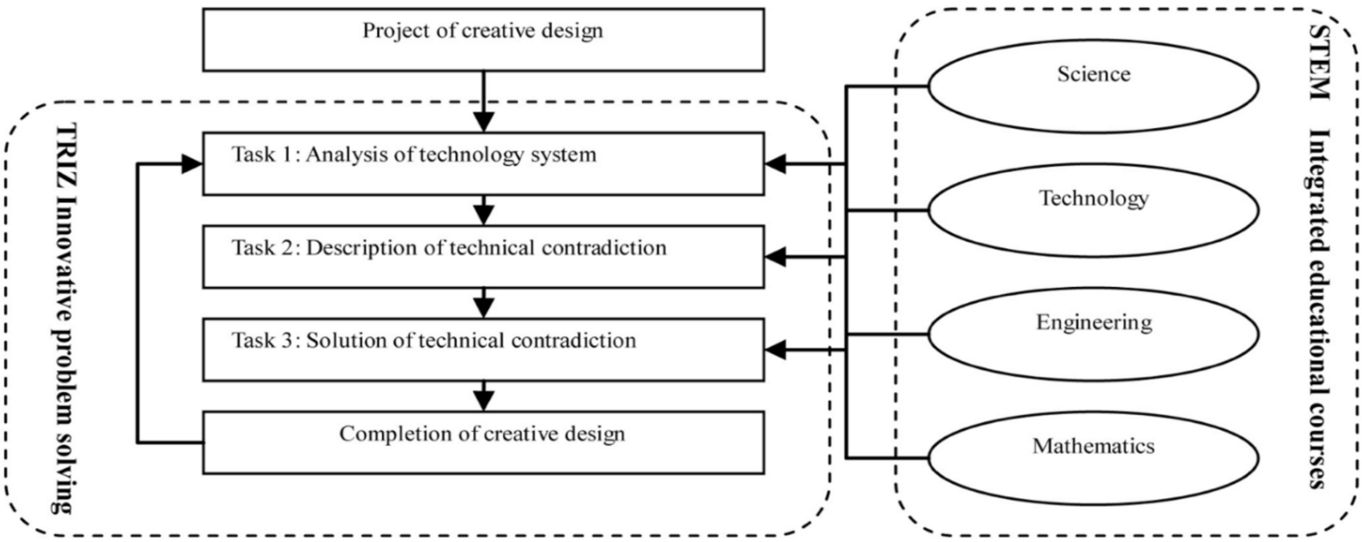


Figure 3. STEM and TRIZ integrated model (Lou et al., 2017)

The STEM teaching model is focused on the understanding skills of the related scientific, technical, engineering and math curricula concept. This can be complement by solving real problem solving through simulation or hands-on experiences (Mohd Shahali et al., 2019). The proposed model has proven to develop a significant impact on the student's skills in solving a real problem and generate effective creative solutions (Lou et al., 2017). The proposed model is supported with systematic methods of TRIZ problem solving that able to guide and assist various levels of students in adopting the model. The steps allowed students to use various problem-solving strategies in developing faster, better and cost-effective solutions for the focused problem Casner et al., 2018). The TRIZ methods were able to provide opportunities for the student in exploring creative solutions that coming from outside the domain of original knowledge and scope of the problem (Jafari & Zarghami, 2017).

The Adaptation and Alignment of TRIZ Problem Solving Framework for Secondary Education

TRIZ practice in industrial applications is analysed in many different ways, to develop new goods, services and technology from the perspective of value and income (Spreafico & Russo, 2016; Abdul Rahim & bin Abu Bakar, 2016; Zulhasni & Nooh, 2015). There are also various types or methods of TRIZ application from one organization to another, which indicates that TRIZ concepts, tools and techniques can be adopted using different frameworks and procedures in applying them (Renjith et al., 2018; Zainali et al., 2019; Rahim & Bakar, 2013). TRIZ has the potential to be adopted together with other similar domain of problem-solving, creativity tools or innovation techniques, such as Six Sigma, Design to Cost, and other concepts applied commonly in industrial practices (Wang et al., 2016; Weijie, 2020; Bakar & Rahim, 2014). In the general context of adopting TRIZ, Altshuller produced the basic framework in problem-solving that starts with analysing the focus specific system, establishing the actual contradiction using TRIZ techniques, and applied TRIZ tools of systematic procedure that guide towards inventive concept solutions, as shown in Figure 4 (Altshuller, 1999).

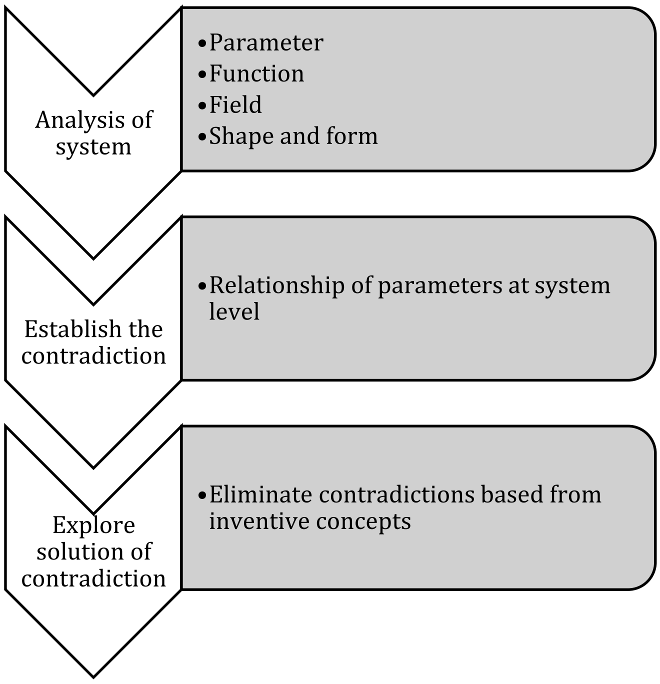


Figure 4. Framework of solving the inventive problem by Altshuller (Altshuller, 1999)

The system has become more complex, also known as ARIZ, the acronym for the Russian term "Algorithm for Creative Problem Resolution". Figure 5 shows how the complexity of the framework can be increase with the same fundamental of TRIZ concepts, tools, and techniques according to the level of complexity in the problem solving (Altshuller & Victory, 1985). Therefore, TRIZ is adaptable based on the context of the situation and application needed by the organization to achieve its goals (Russo et al., 2011; Livotov et al., 2011).

Within education, the structure can be consistent with the background or needs of the STEM-related secondary school curriculum (Belland, 2017). The alignment is critical to ensure that the process of teaching and learning can be carried out by the teachers, students and other supporting elements in the school. If the level of complexity is too high for the teaching and learning process, it will be a burden for either teacher or student to achieve the desired level of problem-solving skills in the STEM-related subjects (English, 2017). This includes the design and the nature of the TRIZ framework and tools that are important for problem-solving activities. Furthermore, TRIZ can be embedded into existing problem-solving programs such as Problem Based Learning (PBL) that allow guidance in the teaching and learning process (Lee, 2019; Li et al., 2019).

Because of the design of the systemic procedures for educational and learning programmes, TRIZ is ideal for PBL (Hung, 2016). Both teacher and student able to work together in understanding problems and explore their inquiries for inventive solutions. The student can utilise their resources and other tools such as the Internet to support them as online digital tools in their program (Batemanazan et al., 2017). Hence, the problem-solving framework is conducive towards 21st-century education programs and used TRIZ as the core tools and techniques for STEM-related activities (Kiong et al., 2017). A study has proposed a framework that focuses on the alignment of STEM-related subjects and the TRIZ problem-solving method (Lou et al., 2013). The framework provides support to the PBL program in the context of exploring inventive solutions for their real problem. The proposed integrated framework used Case experimental instruction to construct the outcome of students' understanding about the real problem and the result of synthesis they produce towards the inventive solutions that they achieved.

A survey of questionnaires has been administered, students are analysed and peer-base participation or other digital online resources have been deployed in Figure 6. The study has shown the positive relationships between the deployment of an integrated framework and learning outcomes such as effectiveness, attitude, and creativity (Lou et al., 2013).

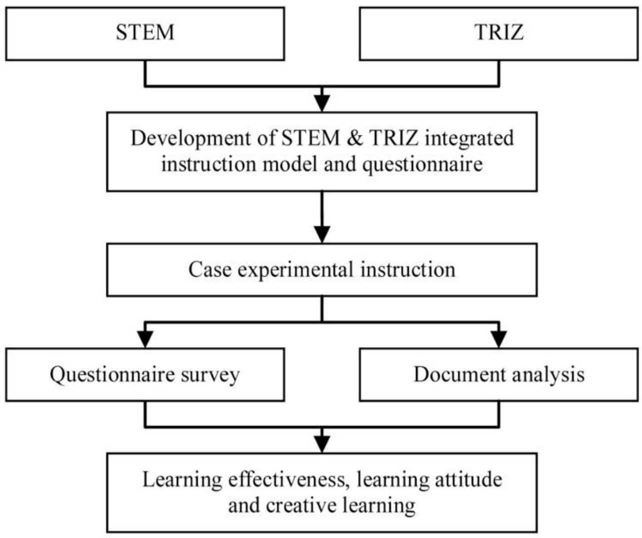


Figure 6. The Integration framework between STEM and TRIZ (Lou et al., 2013)

As a result, the TRIZ can be used to help students apply basic concepts of science, mathematics, engineering theory and technology to facilitate their ability to incorporate STEM education. Furthermore, learning effectiveness is also improved through the PBL competition activity and the discussion mechanism of the online learning platform. The findings of this study reveal that students can be motivated to become active learners with positive learning attitudes with the TRIZ to guide their STEM knowledge learning through PBL activities (Lou et al., 2013).

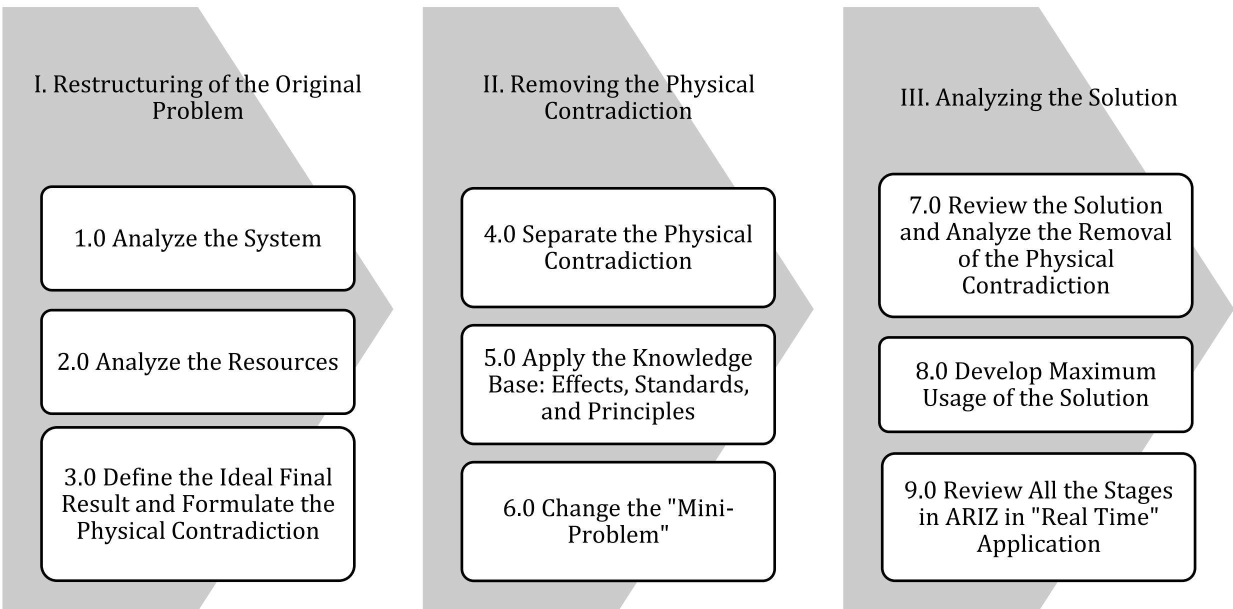


Figure 5. Macro flow chart for ARIZ Altshuller & Victory, 1985)

Theory of Inventive Problem Solving (TRIZ) in Design and Technology Subject

TRIZ has been widely used in Malaysia in various industries including automotive, electronics, aerospace and services, as well as in academia (Abdul Rahim & Abu Bakar, 2013). For example, many TRIZ projects have been developed and published in the automotive industries related to design and technology applications (Zulhasni & Nooh, 2015; Rahim & Bakar, 2013; Rahim & Bakar, 2016). Several TRIZ applications in product design and development are shown significant value to the Malaysian industries that critical for problem-solving skills (Bakar & Rahim; 2014; Rahim & Nooh, 2014; Rahim et al., 2015). TRIZ knowledge and application also provide a significant impact on the industries through cost reduction in the context of design and technology (Abdul Rahim & Bakar, 2016). Some studies of TRIZ applications in Malaysia expand to business innovation and market strategy for design and technology scopes (Zulhasni et al., 2015; Abdul Rahim & Abu Bakar, 2016). This has created strong motivation and potential in adopting TRIZ in the Malaysian Education curriculum, especially for Design and Technology subject.

The task force committee in the Curriculum Division of the Ministry of Education of Malaysia conducted various studies to achieve the design and technology targets of national high-school students. Various knowledge, tools, and techniques have been explored on the problem-solving competencies for secondary school students, including Kaizen, design thinking, computational thinking, mathematical thinking, brainstorming, Theory of Inventive Problem-Solving (TRIZ), and other types of creativity and innovation elements.

The committee decided to select TRIZ as the best medium to develop problem-solving skills because of the mechanism of diverging and converging thought processes that blend in a systematic and structured methodology. The TRIZ methodology has been seen as a problem-solving approach that covers critical innovation theories such as open system theory, dialectical theory, computational thinking, and evolutional theory (Rahim et al., 2018). Figure 7 showed the relationship between TRIZ and the four critical innovation theories for the Design and Technology subject from educational perspectives.

TRIZ can use an integrated innovation theory model and thought model to develop problem-solving skills for the field of design and technology. The relevant TRIZ tools that suitable and aligned with the integration model are shown in Figure 8.

The first TRIZ factor concentrates on the initial problem-solving phase to define the inventive problem with a high value for innovation. This enables students to investigate the value of the problem from the customer point of view and technological current state from the design and technology of the product. The ability to categorize types of problems is essential to form students' competency on how to think about the impact and the outcome in solving a problem (Wits et al., 2010). This skill is significant to customer value creation and developing commercialization value.

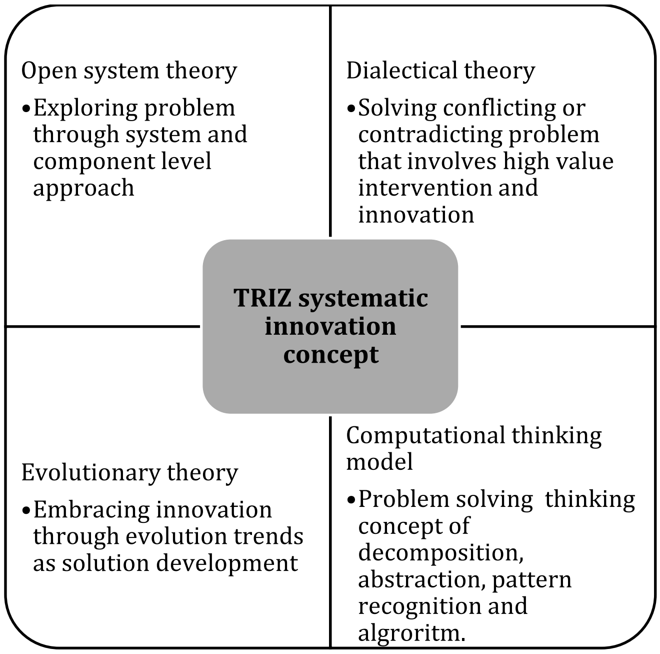


Figure 7. Integration model of innovation theories and model with TRIZ for Design and Technology subject

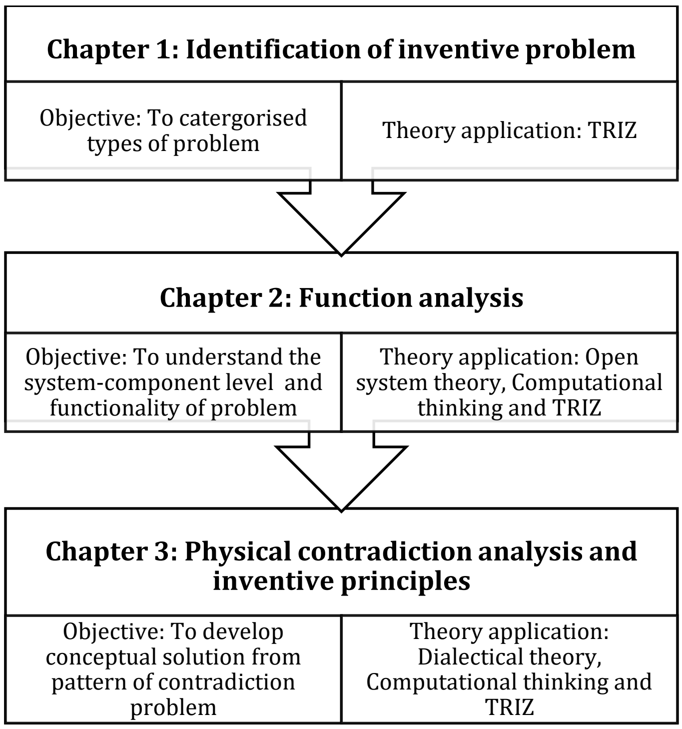


Figure 8. The application TRIZ tools with integrated innovation theories for standard content for Design and Technology subject

In 2018, the latest textbook on design and technology has been released for the first time to all secondary schools in Malaysia (Zukhairi et al., 2017).

Figure 9 shows the textbook that has been used for teachers and students that incorporates Design and Technology subject as their elective program. In the textbook, TRIZ tools that have been introduced based on the Secondary School Standard Curriculum are the categorization of inventive problem, the application of functional analysis of focus problem, the application of cause-effect chain analysis for identifying root causes, developing a model of problem using physical contradiction and the application of selected inventive principles for concept solution generation using creativity skills.

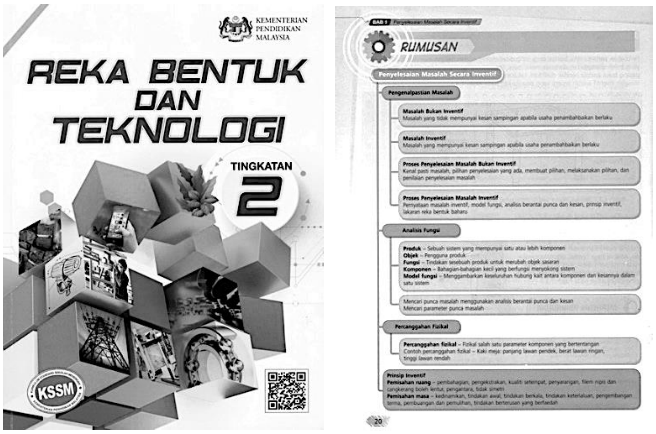


Figure 9. The new textbook of Design and technology subject and TRIZ topics

Results and Discussion

The new design and technology textbook application has been taught in schools since 2018 along with the TRIZ implementation. A feedback form has been deployed to the participants on the understanding, application, and impact of TRIZ in the Design and Technology subject. The survey has been deployed to 1032 respondents. As shown in Figure 10, the majority of the respondent are teachers with 91% of the total respondents. 72 students are also involved in the study and representing the feedback of the learning experience. The rest of the respondents are from non-academic representatives.

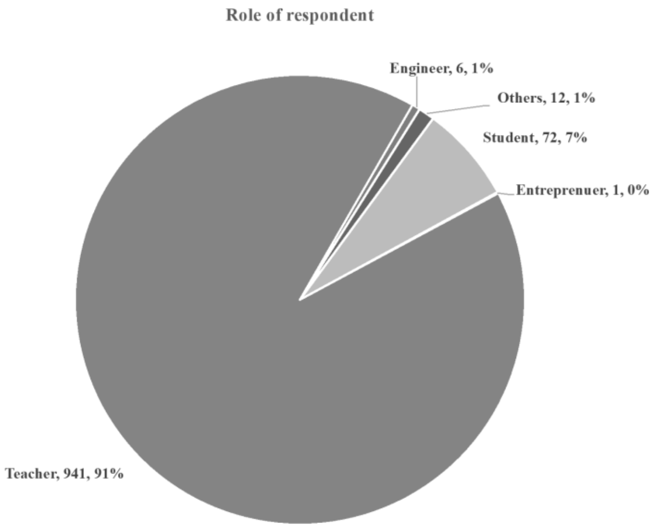


Figure 10. The role of the respondent for the study

In 16 states in Malaysia, the survey was conducted, and the largest groups were Johor (204), Selangor (169) and Kuala Lumpur (149 respondents), which are shown in Figure 11.

The feedback form also explored the experience in teaching and learning TRIZ for Design and Technology subject by the respondents. The result has shown that 71% or 728 respondents have strongly agreed that they have valuable experience from teaching and learning TRIZ. Another 28% or 288 respondents agreed on a similar statement, as shown in Figure 12.

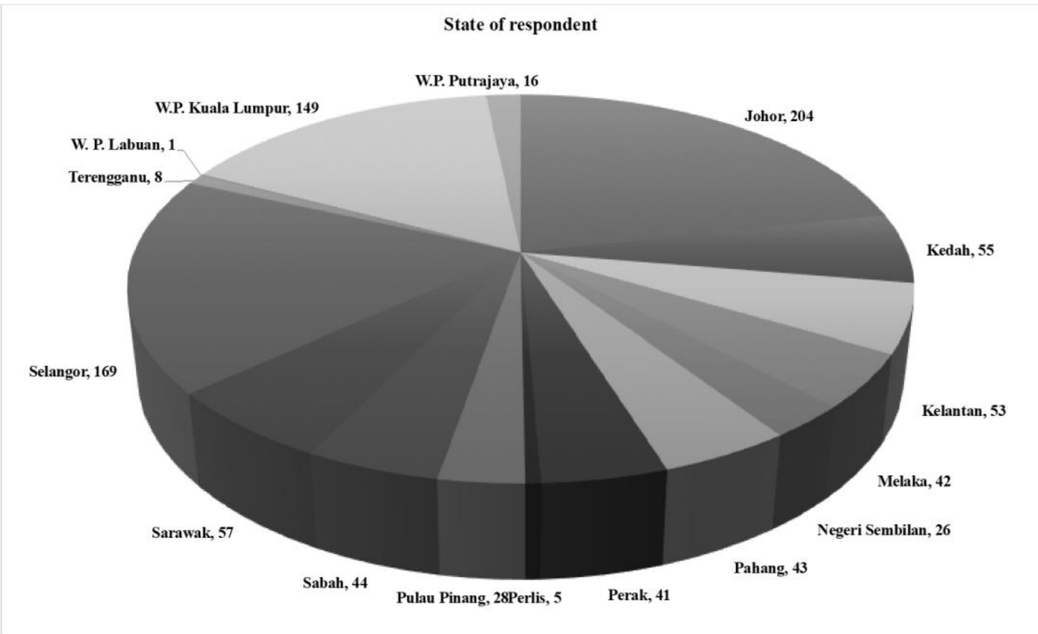
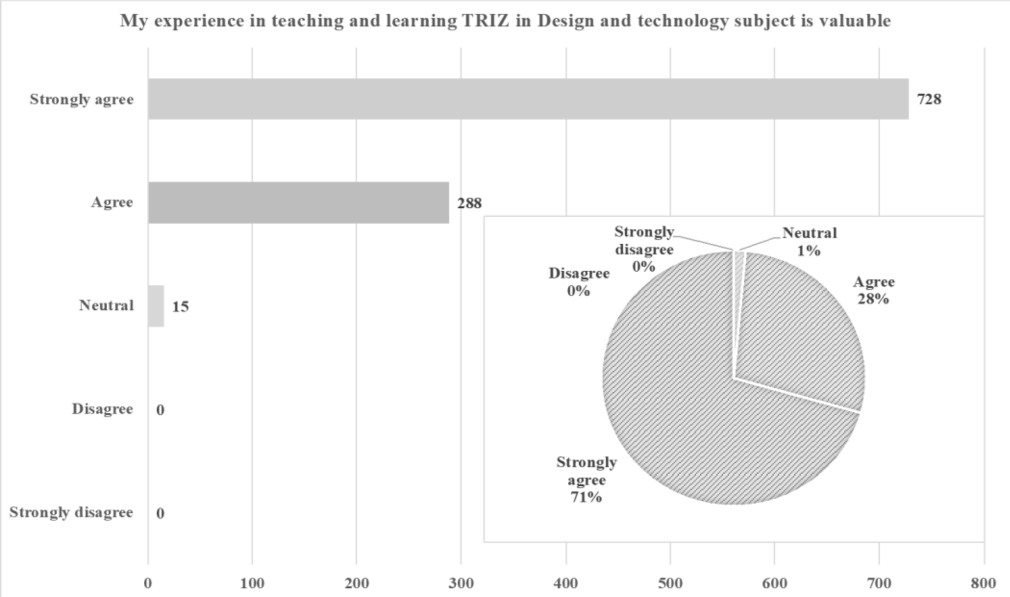


Figure 11. The state of the respondent for the study



	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
Grand Total	0	0	15	288	728

Figure 12. The respondent level of valuable experience in teaching and learning TRIZ

The survey also received comments on TRIZ's work in the area of design and technology. Figure 13 demonstrates that 93% or 963 of the intimates' consent to TRIZ in the matter. However, the rest of the respondents are disagreed (2 respondents) and unsure (60 respondents) about it. These responses have prompted more probing questions to understand the underlying issues of teaching and learning for TRIZ and might lead to some suggestions for improvement of the processes.]

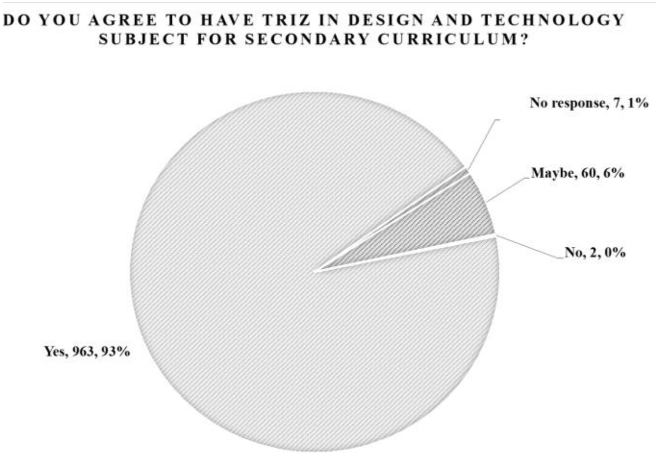


Figure 13. Respondents feedback in having TRIZ in Design and Technology subject

The respondent asked about the key factors to improve the success of TRIZ's adoption on the subject. The result shows that the three main factors are the process of explaining the application of TRIZ for the Design and Technology subject, the application of the TRIZ knowledge in the classroom and the extension of supporting knowledge and practices for TRIZ in the subject, as shown in Figure 14.

The data indicate that about 80% of teaching and learning questions are important and have to be dealt with accordingly. Both teachers and students should able to carry out the teaching and learning process with a clear and practical explanation. The process should adopt a simple and relevant example in having a better understanding of a problem, and the role of TRIZ during the process (Hui & Zhijian, 2005). Based on the data, it is also critical for the process to apply the TRIZ to various types of examples and project cases. This strengthens the confidence of the teacher and student in completing the subject (Belski et al., 2013). Furthermore, the process of teaching and learning must not stop only in the classroom, but also extended to their daily life, extending their knowledge on TRIZ, improve the skills of problem-solving, and even extending the TRIZ application beyond the subject of Design and Technology (Lepeshev et al., 2013).

The respondents' feedback offers an understanding of how to learn new creative and innovative instruments such as TRIZ. The teacher and student offer feedback about the understanding of effective problem-solving skills especially on the inventive problem of TRIZ present in real life (Chang et al., 2016). The feedback indicates that a higher level of creativity and innovation are important for teachers and students, specifically for the Design and Technology subject (Wits et al., 2010).

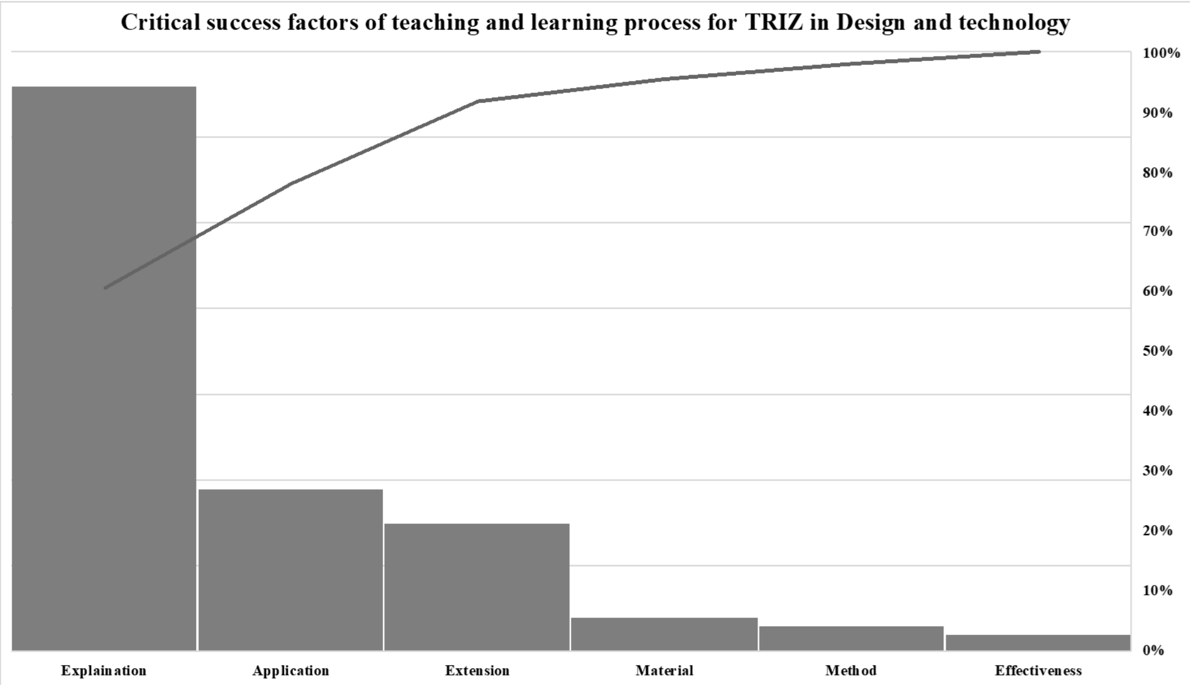


Figure 14. Pareto analysis of issues in teaching and learning TRIZ in Design and Technology subject.

Conclusions

This paper highlighted the crucial mechanism for TRIZ in the Malaysian curriculum to develop imagination, innovation and skills of students in complex problem-solving. The implementation process started with policy development, curriculum design, the introduction of TRIZ for secondary school level, the development of textbooks, the implementation process of teaching and learning, the feedback for continuous improvement.

The incorporation of TRIZ into the mainstream national training curriculum has led to a progressive increase in student problem-solving skills. The success of the Malaysian education system can be an example and benchmark for other countries that face similar and more significant challenges in making TRIZ a part of the catalyst for future generations

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