A Scaffolding Framework Using Mind Maps and Metacomponents to Improve Real-World Physics Problem-Solving Skills

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Abstract

Traditionally, physics problem-solving has mainly focused on mathematical procedures and quantitative analysis, often leading students to rely on memorization and repetitive drills. However, introduction to real-world physics problem-solving (RWPPS) has proven to provide students with skills that can be applied in various real-world situations beyond the classroom. RWPPS is considered a complex problem-solving process with a combination of multiple skills, making it challenging for students. Metacomponents are higher-order control processes that are used for planning how a problem should be solved, deciding on which strategy should be used during problem-solving and monitoring the success of one's problem-solving. Therefore, this paper synthesizes literature in RWPPS and metacomponents to develop a conceptual framework to implement a suitable scaffolding strategy for pre-university students to improve their RWPPS skills. Vygotsky's theory of Social Constructivism, which is based on the concept of Zone of Proximal Development (ZPD), is used as a basis for evaluating the development of students' skills in RWPPS. This framework incorporates mind maps as a scaffolding tool and metacomponents as an executive process to assist students in planning, monitoring, and evaluating their problem-solving process. Through this proposed framework, it is hoped that students will be able to surpass their ZPD, providing a more structured teaching approach to solving real-world physics problems and enhancing their skills to meet the challenges of the 21-st century.

Keywords: concept paper, real-world physics problem-solving, metacomponents, scaffolding, mind map

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Introduction

In shaping the future of education, it's crucial to establish a strong groundwork for students, ensuring they acquire the diverse skills necessary for success in the 21st century. This involves honing their core learning abilities, fostering a deep understanding of concepts, and cultivating effective problem-solving skills (Bao & Koenig, 2019; Lai & Viering, 2012). Therefore, in physics education, physics teaching & learning will always remain the focus in ensuring that the resulting graduates are always in line with the needs of the 21st century. The core components applied in physics learning, such as conceptual understanding and problem-solving, always remain the current emphasis and this aligns with higher education's needs by preparing graduates to be problem-solving providers (Kementerian Pendidikan Malaysia, 2015). Physics subjects can serve as an ideal introduction to help students develop problem-solving skills. They provide students with knowledge about the laws of the real-world (Bancong & Song, 2020) and present them with problems to solve (Halilović et al., 2021; Sutarja & Wulandari, 2021), which encourages their critical thinking not only in the realm of physics but also in addressing problems outside of science (Chiu et al., 2022; Mafarja et al., 2022).

In the context of the physics curriculum in Malaysia, one of the goals of the physics course is to strengthen students' problem-solving skills, not only at the secondary level but also at the higher education level in universities (Agensi Kelayakan Malaysia, 2019; Bahagian Pembangunan Kurikulum, 2018). Therefore, to achieve this goal, it is crucial to ensure that students are always equipped with strong physics problem-solving skills and can make decisions in daily life. This is consistent with the educational goals outlined in the Malaysian Education Development Blueprint 2013-2025, which aims to produce knowledgeable and highly skilled citizens capable of competing on an international level (Ministry of Education Malaysia, 2015).

As a response, in this era, it is important to practice teaching and learning that can improve students' physics problem-solving skills, particularly in real-world physics problem-solving (RWPPS). This is because students who engage in physics problem-solving especially real-world problems, have the potential to hone their skills in solving problems and can improve their understanding of concepts and decision-making (Niss, 2012; Pulgar et al., 2021). Furthermore, real-world physics problem-solving is synonymous with integrating various needed skills, especially skills in the 21st century (Adams & Wieman, 2007; Ince, 2019).

Problem Background

To improve students' real-world physics problem-solving skills, they need to be exposed to problem-solving processes that can help them become more expert in problem-solving. Providing structured and effective support through systematic and good scaffolding can help students become more skilled in real-world physics problems-solving (RWPPS), especially by guiding them through the process of solving the problem. However, according to Docktor et al. (2016), problem-solving in physics is still seen as a traditional learning that emphasizes mathematical procedure skills and quantitative analysis. This means that solving physics problems often results in memorization-oriented learning compared to real understanding.

When we refer to RWPPS, it involves a more complex process than memorizing answers. Physics problem-solving, especially real-world problem-solving, is often associated with solving complex problems. This is because it requires dealing with a problem statement that combines various types of representations, such as symbols, graphs, diagrams (Kohl & Finkelstein, 2008; Kook & Novak, 1988; Küchemann et al., 2021; Murshed et al., 2021), mathematical expressions (Küchemann et al., 2021; Murshed et al., 2021), large amounts of text (Reinhold et al., 2020) and entails solving actual problems encountered in daily life (Ince, 2018; Pulgar et al., 2021). Moreover, RWPPS also demands a process of acquiring and organizing information to solve problems accurately and effectively (Pulgar et al., 2021; Vignal & Wilcox, 2022, 2021).

At the higher education level, most physics problem-solving involves RWPPS (Docktor et al., 2016). This is because RWPPS presents a learning situation that comes from real experience and knowledge in justifying ideas and decision-making. In addition, real-world problem-solving is more prone to various possibilities that are more open to the approach and results given, which is more significantly known as an ill-structured problem (Sarathy, 2018). Based on previous studies, most of the problems that are practiced at the institutional level are more geared towards structured problems (well-structured problems) because of their nature, which is more transparent and more accessible to understand and easily solved by students (Balasubrahmanya & Merra, 2012; Morphew et al., 2020; Ndiaye et al., 2022; Pulgar et al., 2021), whereas problems involving real-world problem-solving are more open-ended.

Another researcher also supports this point, in which most real-world problem-solving is unclear to a certain extent, lacks the necessary information, and does not have an accurate final answer condition (Fortus et al., 2005). Hence, the solution to this problem also does not have a correct or best solution. Then, it is not surprising that researchers have introduced various methods and strategies to achieve the goal of making students proficient in solving real physics problems; among them is by encouraging collaborative groups between students (Leak et al., 2017), drawing diagrams (Vignal & Wilcox, 2021), placing various visual or graphic representations (Munfaridah et al., 2021; Setyarini et al., 2021), transformation of multiple representations (Murshed et al., 2021), problem manipulation (Siburt et al., 2011), computer simulation (Park, 2020) and so on.

Nevertheless, one of the crucial aspects of problem-solving is how it is learned and presented to students, which aims to guide them to improve their problem-solving skills (Teodorescu et al., 2013; Weisberg, 2020). Therefore, since metacomponents are higher-order cognitive processes involved in the problem-solving process (Sternberg, 1985), then this metacomponents process should also be implemented to help students regulate their thinking through the process of planning, monitoring, and assess understanding when solving real-world physics problems. By integrating this metacomponents, the student can also indirectly improve their RWPPS skills and make them more effective. Based on the information, arguments, and evidence stated in the background of the problem, there is empirical evidence showing that real-world physics problem-solving needs to be learned by students, especially in the process of solving the problem through the correct and relevant support scaffolding used.

Through the lens of this study, apart from the instructor, the mind map can also serve as a scaffolding that is used as an aid in solving real-world physics problems. This is because mind maps are seen as able to strengthen the metacomponents processes involved in a structured and detailed way through appropriate strategy planning, which includes awareness of a person's thought process, understanding of cognitive patterns, and controlling the cognition involved (Dhindsa et al., 2011; Sternberg, 1985; Sternberg et al., 2008). On top of that, a mind map is not just a source of support, but rather, it helps students in the process of solving the problem itself through organizing solution steps, planning strategies, representing problems, organizing information, monitoring and evaluating the entire solution process (Sari et al., 2021). Like the metacomponents process, incorporating mind maps in RWPPS can directly inspire students to enhance further their ability to explore the relationship between information, improve thinking skills, and foster creativity by generating innovative ideas (Sun et al., 2022), which in the end students can solve real physics problems successfully.

In previous studies, various learning approaches have been examined. However, there has been a lack of focus on developing a structured learning framework for scaffolding to improve problem-solving skills, particularly at the pre-university level. Therefore, this study proposes a framework for implementing scaffolding that integrates mind maps and metacomponents as an executive process in RWPPS, and explains how this scaffolding improves pre-university students' real-world physics problem-solving skills.

Literature Review

Researchers believe that one of the important ways to improve students' problem-solving skills is based on the scaffolding used (Arifin et al., 2020; Sukariasih et al., 2020). According to Govindasamy and Kwe (2020), when the proper scaffolding is given to students at their potential development level, it will further increase their problem-solving ability (Govindasamy & Kwe, 2020). This can also make learning more effective because students learn to solve problems according to their abilities (Saputri & Wilujeng, 2017). This is supported by Vygotsky, (1978) in his Theory of Social Constructivism, who believes that teaching activities with appropriate support given to students in the Zone of Proximal Development (ZPD) can further increase the ability of students to complete the tasks given. In the problem-solving, students should receive some support or scaffolding to ensure that they are within the most effective Zone of Proximal Development (ZPD) and can solve problems successfully (Kusmaryono et al., 2021). Furthermore, this matter considers student development, including through guidance from instructors (Suardipa, 2020), collaboration with more expert peers (Kusmaryono et al., 2021; Pulgar et al., 2021), diverse teaching strategies or methods (Govindasamy & Kwe, 2020) or tools capable of leading students in the ZPD (Daley, 2004; Zimmerman et al., 2011).

In RWPPS, students need to use critical skills and strategies based on their knowledge and experience (Thohir et al., 2020). Learning topics in physics according to the context of daily life can make learning more enjoyable for students. However, if students solve problems without the necessary skills, strategies, or experience, they are likely not learning meaningfully. Therefore, mind maps are practical thinking tools that can be used as a scaffolding tool to enhance student performance in physics (Akanbi et al., 2021). In addition, many researchers agree that mind maps are not only a potential strategy to be used in learning but mind maps are also a support that makes learning more meaningful by building new ideas, representing knowledge and concepts, constructing relationships that are needed during problem-solving, as well as helping to motivate students to be more innovative and creative (Alkilany, 2017; Dong et al., 2021; Sun et al., 2022). Mind maps also generate ideas and trigger students' memory of existing knowledge. Additionally, mind maps can be used to develop students' brain potential by representing visual and graphic images during the problem-solving process. In a study conducted by Sun et al., mind maps can be used as an effective scaffolding tool for idea generation and information organization (Sun et al., 2022). This is because mind maps can organize and connect ideas to enable students to visually represent information by forming branches that connect related concepts (Chen et al., 2022). With that, mind maps can help students see the relationship between ideas and further facilitate their understanding, and retention of knowledge.

In the Triarchic Theory, Sternberg (1985) states that problem-solving involves higher-order executive processes known as metacomponents, among which are problem recognition, definition, and representation. The metacomponents proposed in this theory is in the branch of the componential sub theory, which aims to guide student problem-solving through skill activities such as planning, monitoring, and evaluating the problem-solving process (Culatta, 2022; Sternberg, 1985). Besides that, according to Pretz et al. (2003), Sternberg (2003) and Sternberg & Sternberg (2017), among the problem-solving processes that involve scientific thinking and are contained in the metacomponents namely (i) recognizing the existence of a problem, (ii) defining the nature of the problem, (iii) making a representation of the problem, (iv) determine the resources to solve the problem, (v) form the strategy or steps needed to solve the problem, (vi) monitor the problem-solving process while it is being implemented, and (vii) evaluate the problem-solving done after the problem-solving has been completed.

When solving complex problems such as ill-structured problem-solving, the metacomponents is an executive process that plays an important role in the problem-solving process (Pretz et al., 2003; Veselinov & Nikolić, 2015). This process requires basic knowledge and skills. It involves higher-order cognitive functions that allow individuals to plan, strategize, and coordinate their efforts more effectively. On that basis, in physics, when related to real-world problem-solving, the problem's solution can be categorized as unstructured problem-solving because of its complex nature (Xing et al., 2022). This is because RWPPS does not only depend on conceptual knowledge nor knowledge of the subject alone, but it requires holistic problem-solving skills, including analyzing problems (Ganina & Voolaid, 2015; Lestari & Deta, 2021), breaking information to manageable parts (Xing et al., 2022), identify related principles and concepts (Hidayati & Ramli, 2018; Reddy & Panacharoensawad, 2017), and formulate appropriate problem-solving approaches (Hakim et al., 2022). So, with that, metacomponents act as a guide to forming an effective problem-solving process.

In RWPPS, initial phases, such as problem recognition, definition, and representation, are critical to solving the problem accurately and efficiently (Hakim et al., 2022; Pretz et al., 2003). Suppose the process in the initial phase of physics problem-solving is not emphasized and prioritized during teaching and learning with students. In that case, the subsequent problem-solving process will experience difficulties, and the problem-solving will be less accurate (Pulgar et al., 2021). A study found that students who were guided earlier in the problem-solving process could define the problem well, subsequently successfully solving the problem more accurately (Pulgar et al., 2021). In general, solving a problem that is not well-defined gives less satisfactory results compared to solving a problem that is better defined (Ince, 2019; Teodorescu et al., 2013).Based on the facts above, the combination of metacomponents and mind maps is a practical scaffolding framework for guiding and organizing problem-solving, particularly in real-world physics problem-solving. By utilizing their functionality, students can improve their problem-solving skills, confidently approach complex physics problems, and ultimately achieve successful results.

Conclusion and Recommendation

This study presents a framework that utilizes a mind map, combining metacomponents and constructivism theory to support real-world physics problem-solving. The framework encourages critical thinking and a deep understanding of physics concepts through organized mind maps. Incorporating constructivist theory lays the groundwork for meaningful learning through active experience. Metacomponents, on the other hand, offers structures and strategies to assist students in planning, monitoring, and evaluating their problem-solving processes. This integration enables students to break down complex problems, comprehend the connections between concepts, and develop effective solution strategies. This scaffolding helps students enhance their skills in solving more complex physics problems and overcome challenges encountered in real-world problem-solving.

Besides that, this study has also made an important contribution to the emergence of new knowledge in using scaffolding to improve students' real-world physics problem-solving through a scaffolding framework. This study is conducted to develop new knowledge based on the philosophy of social constructivism, especially regarding the combination of the role of mind maps and metacomponents. The results of this study also open opportunities for further empirical research on the effectiveness of this framework by emphasizing various learning contexts to ensure broad applicability and effectiveness, especially in the philosophy of social constructivism. In terms of contribution to learning practices, making full use of the potential of this framework can provide students with the structure and support needed to help them become more skilled during the problem-solving process. Teachers can use this approach in their teaching and learning to help students overcome challenges in real-world physics problem-solving and prepare them to face real-world situations more confidently and competently. By supporting students through mind maps and metacomponents, teachers can provide a more holistic and practical learning experience. This study also contributes to physics education theory and offers practical strategies for educators to improve students' problem-solving skills in real-world contexts.

Overcoming the perception of physics as a complex subject, this framework provides structured support that promotes critical thinking and deep understanding. By integrating mind maps and metacomponents, this framework helps students actively engage with physics concepts and improve their problem-solving ability. The proposed Scaffolding framework, as shown in Figure 1, can be further explored in the future by applying other skills. Therefore, this framework can be valuable in improving physics teaching and preparing students to face future challenges.

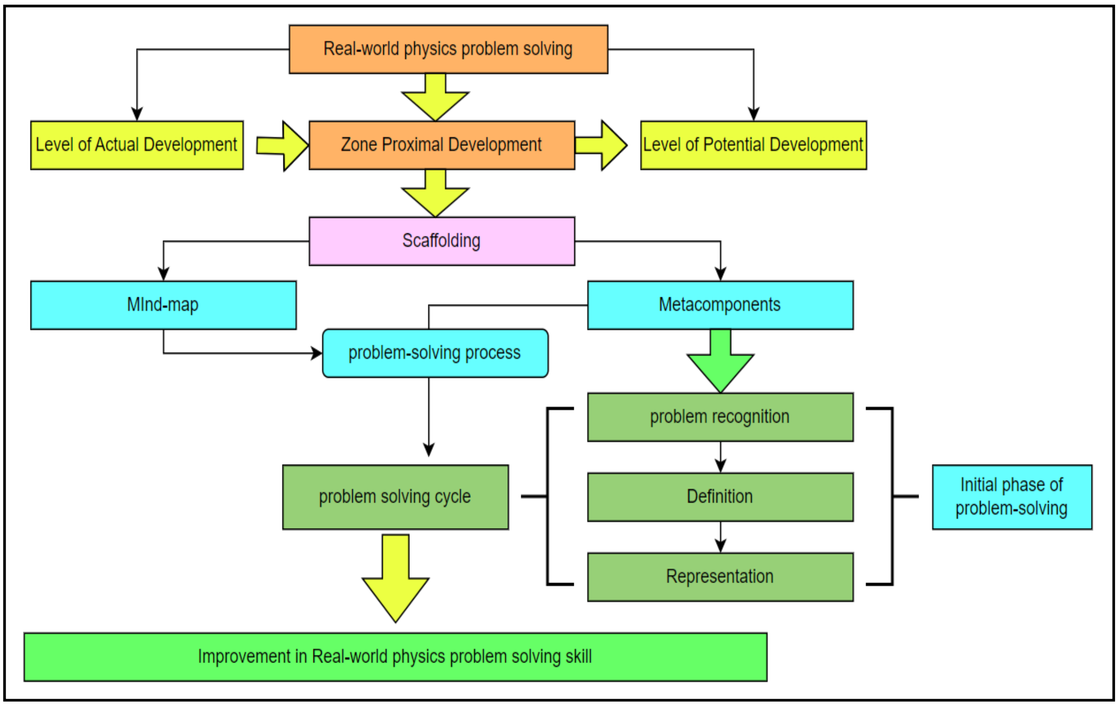

Fig. 1 Proposed scaffolding framework in improving real-world physics problem-solving

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