15 (2) (2026) 228-234

Unnes Science Education Journal

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Development of the PBL-STEMR Model on the Earth and Solar System Topic to Enhance Religious Literacy and Metacognitive Knowledge of Madrasah Tsanawiyah (MTs) Students

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DOI: http://dx.doi.org/10.15294/usej.v15i2. 45370

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Article Info

Submitted 2026-05-03
Revised 2026-07-01
Accepted 2026-08-29

Keywords

Metacognitive knowledge; PBL-STEMR; Religious literacy

Abstract

The low integration of religious values in Natural Science (IPA) learning and the suboptimal development of metacognitive knowledge among students of Madrasah Tsanawiyah (MTs) have become issues that require serious attention. Science learning tends to focus on the cognitive aspects of science and separates scientific knowledge from religious values, particularly in the topic of Earth and the Solar System, which actually has a strong connection with religious values. This study aims to develop a Problem Based Learning model integrated with Science, Technology, Engineering, Mathematics, and Religion (PBL-STEMR) and to analyze its feasibility and effectiveness in improving the religious literacy and metacognitive knowledge of MTs students. This research is a Research and Development (R&D) study that refers to the ADDIE model, which includes the stages of analysis, design, development, implementation, and evaluation. The product developed is the PBL-STEMR learning model along with its supporting instructional components. The feasibility of the model was tested through expert validation, while the effectiveness of the model was analyzed based on the measurement results of students' religious literacy and metacognitive knowledge after the implementation of the model. The results of the study indicate that the PBL-STEMR model is considered feasible for use based on expert evaluations. Furthermore, the implementation of the PBL-STEMR model has been proven to be effective in improving the religious literacy and metacognitive knowledge of MTs students in the topic of Earth and the Solar System. This study concludes that the PBL-STEMR model is a feasible and effective innovative approach for integrating science and religious values while enhancing students' metacognitive knowledge. It is recommended as an alternative for science learning in MTs to support holistic education, balancing scientific understanding and religious character development.

How to Cite

Marom, K., Alimah, S., Marianti, A., Ellianawati, E., & Widiyatmoko, A. (2026). Development of the PBL-STEMR Model on the Earth and Solar System Topic to Enhance Religious Literacy and Metacognitive Knowledge of Madrasah Tsanawiyah (MTs) Students. *Unnes Science Education Journal*, 15(2), 228-234.

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p-ISSN 2252-6617

INTRODUCTION

National education emphasizes the importance of balancing the mastery of knowledge, skills, and the development of religious character as a foundation for building high-quality human resources with strong moral values. Education is not only oriented toward cognitive achievement but also toward strengthening the affective and spiritual dimensions of students (UNESCO, 2022; OECD, 2021). In this context, science education plays a strategic role, as it is expected not only to develop scientific literacy but also to contribute to character formation (Bybee, 2021; Li et al., 2023). However, in practice, the integration of scientific concepts and religious values in science learning has not been implemented systematically. Learning tends to focus on the acquisition of scientific knowledge, while reflective, ethical, and spiritual dimensions receive less attention. This condition leads to a dichotomy between science and religion in the learning process, resulting in the suboptimal achievement of holistic educational goals (Hidayati & Suyadi, 2021; Rahman et al., 2022).

This issue becomes increasingly complex when associated with the characteristics of Generation Z, who grow up in a highly digitalized environment with rapid and unlimited access to information. While this generation demonstrates strong digital literacy and adaptability, they are also vulnerable to value degradation, moral disorientation, and weak self-regulation if not supported by adequate character education (OECD, 2021; Bond et al., 2022). Recent studies also indicate that excessive exposure to digital information without value filtering may negatively affect students' ethical decision-making and social behavior (Cheng et al., 2021; Kim & Choi, 2022). Therefore, learning in the digital era must integrate cognitive, socio-emotional, and ethical dimensions to ensure balanced student development (Bond et al., 2022; UNESCO, 2022). Without integrating moral and spiritual values into the learning process, education risks producing individuals who are intellectually capable but lack ethical responsibility and spiritual awareness. Thus, innovative learning approaches are needed to bridge the gap between intellectual development and moral formation.

The integration of religious values in science learning has been recognized as a strategic approach to address this challenge. Value-integrated learning enhances the connection between scientific knowledge and real-life contexts, thereby promoting meaningful and transformative learning experiences (Lombardi et al., 2021; Widodo et al., 2023). In addition, integrating religious values into STEM-based learning environments has been shown to improve students' moral awareness, scientific attitudes, and engagement in learning activities (Rahman et al., 2022; Fitriani et al., 2022). Other studies indicate that science learning integrated with religious perspectives can increase students' intrinsic motivation, as it makes learning more relevant and personally meaningful (Widodo et al., 2023; Yusuf et al., 2022). Moreover, the incorporation of ethical and spiritual values into science education contributes to the development of responsible and reflective individuals who are better prepared to face global challenges (Hidayati & Suyadi, 2021; Abdullah et al., 2023).

From a global perspective, the integration of values in education is also aligned with the goals of sustainable development, particularly in fostering inclusive and equitable quality education as outlined in Sustainable Development Goal 4 (SDG 4) (UNESCO, 2022). Education systems are increasingly expected to develop not only academic competencies but also character, ethics, and global citizenship (OECD, 2021; Torres, 2021). In this regard, integrating religious and moral values into science education can contribute to developing learners who are not only scientifically literate but also socially responsible and ethically grounded (Rahman et al., 2022; Abdullah et al., 2023). This highlights the importance of designing learning models that are capable of integrating knowledge, skills, and values in a balanced and meaningful way.

On the other hand, science learning also faces challenges in developing students' metacognitive abilities. Metacognition is a crucial 21st-century skill that enables students to plan, monitor, and evaluate their own thinking processes. It plays a significant role in improving learning outcomes, critical thinking, and problem-solving abilities (Zohar & Barzilai, 2023; Cheng et al., 2021). Students with well-developed metacognitive skills are more capable of regulating their learning, selecting appropriate strategies, and reflecting on their understanding (Dignath & Veenman, 2021; Panadero, 2022). However, classroom practices often remain teacher-centered, limiting opportunities for students to actively engage in metacognitive processes. Therefore, instructional approaches that explicitly foster metacognitive awareness are essential (Dignath & Veenman, 2021; Panadero, 2022).

Problem-Based Learning (PBL) has been widely recognized as an effective instructional

model for developing metacognitive skills and higher-order thinking. PBL engages students in solving real-world problems, encouraging active participation, inquiry, and reflection (Anazifa & Djukri, 2021; Jiang et al., 2022). Empirical studies have shown that PBL significantly improves students' critical thinking, problem-solving skills, and collaborative abilities (Wang et al., 2022; Suwono et al., 2022). Furthermore, PBL promotes deeper learning by encouraging students to reflect on their learning processes and outcomes (Suwono et al., 2022; Hmelo-Silver et al., 2022). These characteristics make PBL a suitable approach for addressing the challenges of 21st-century education.

The integration of PBL with the STEM (Science, Technology, Engineering, and Mathematics) approach further enhances its effectiveness. STEM education provides interdisciplinary and contextual learning experiences that enable students to apply knowledge from multiple domains to solve complex problems (Bybee, 2021; Li et al., 2023). Research indicates that the integration of PBL and STEM significantly improves students' critical thinking and metacognitive skills (Mulyadi et al., 2021; Jiang et al., 2022). Additionally, STEM-based learning contributes to the development of self-regulated learning and metacognitive awareness (Putri et al., 2022; Panadero, 2022). It also enhances student motivation, creativity, and engagement in learning activities (Margot & Kettler, 2022; Fitriani et al., 2022). Recent studies further highlight that STEM education fosters innovation and problem-solving skills, which are essential for addressing contemporary global challenges (Li et al., 2023; Becker & Park, 2022).

The development of PBL-STEM-based instructional materials has also been shown to be valid and effective in improving students' metacognitive abilities. These materials support students in planning, monitoring, and evaluating their thinking processes more effectively (Rahmawati et al., 2023; Mulyadi et al., 2021). At the same time, integrating religious values into learning models has demonstrated positive outcomes. Problem-based learning integrated with religious values significantly enhances students' religious literacy and moral awareness (Aini & Fathurrohman, 2023; Abdullah et al., 2023). Moreover, science learning oriented toward religious literacy has been found to improve students' metacognitive awareness, as it encourages them to reflect on the meaning and implications of scientific knowledge in their daily lives (Huda et al., 2024; Yusuf et al., 2022).

Despite these promising findings, most existing studies have examined PBL, STEM, and religious value integration separately. There is still a lack of research that systematically integrates these three components into a comprehensive instructional model, particularly in the context of Islamic junior high schools (Madrasah Tsanawiyah). Furthermore, studies that simultaneously investigate the impact of such models on both religious literacy and metacognitive knowledge are limited (Rahmawati et al., 2023; Huda et al., 2024). This indicates a significant research gap that needs to be addressed through the development of an integrative and holistic learning model.

In the context of Islamic education, especially in Madrasah Tsanawiyah, the integration of science and religion is not only relevant but essential. Islamic education emphasizes the unity of knowledge, where scientific inquiry and religious understanding are interconnected (Abdullah et al., 2023). Therefore, developing a learning model that integrates scientific problem-solving, interdisciplinary STEM approaches, and religious values is crucial for achieving educational goals that align with both national and religious expectations.

Based on these considerations, this study develops a PBL-STEMR model (Problem-Based Learning-Science, Technology, Engineering, Mathematics, and Religion) on the topic of Earth and the Solar System and examines its feasibility and effectiveness in improving students' religious literacy and metacognitive knowledge at the Madrasah Tsanawiyah level. This model offers novelty through the systematic integration of problem-based learning, a multidisciplinary STEM approach, and the internalization of religious values within a unified instructional design. In addition, this study simultaneously examines two key variables-religious literacy and metacognitive knowledge-which have rarely been investigated together in previous research. Therefore, the PBL-STEMR model is expected to provide an innovative solution for implementing holistic science learning that not only emphasizes conceptual understanding but also fosters religious character, ethical awareness, and reflective thinking skills among students.

METHOD

This study employed a Research and Development (R&D) approach using the ADDIE model (analysis, design, development, implementation, and evaluation) to develop the PBL-STEMR

model for the topic of Earth and the Solar System in Grade VIII of Islamic junior high school (MTs). The ADDIE model was selected due to its systematic, flexible, and effective nature in developing instructional materials and innovative learning models (Branch, 2021; Almelhi, 2022). The analysis phase was conducted through literature review, classroom observations, and teacher interviews to identify the need for integrating religious values and developing metacognitive skills in science learning, which are essential aspects of 21st-century education (Zohar & Barzilai, 2021; UNESCO, 2021).

The design phase included the development of PBL-STEMR syntax, preparation of learning materials, and construction of research instruments based on problem-based learning principles and STEM integration (Kelley & Knowles, 2021; Panadero et al., 2022). In the development phase, the product was validated by subject matter experts, instructional model experts, and practitioners, and subsequently revised until it was deemed feasible in accordance with the validity principles in educational design research (McKenney & Reeves, 2021).

The implementation phase involved a limited trial with teachers and 25 eighth-grade students of MTs Negeri Kota Semarang to examine the applicability of the model in real classroom settings (Akker et al., 2021). The evaluation phase aimed to assess the feasibility and effectiveness of the model using both formative and summative approaches (Branch, 2021).

The data consisted of qualitative data (expert feedback and user responses) and quantitative data (questionnaires on religious literacy, metacognitive knowledge, and model feasibility) measured using a Likert scale, which is commonly used in educational research to assess perceptions and attitudes (Joshi et al., 2022). Feasibility analysis was conducted descriptively in the form of percentages. The effectiveness of the model was analyzed using prerequisite tests (normality and homogeneity) and the Mann-Whitney U test at a significance level of 0.05 to compare the experimental and control groups, particularly when the data were not normally distributed (Nachar, 2021; Mishra et al., 2022). The model was considered effective if there was a significant difference between the two groups.

RESULT AND DISCUSSION

The development of the Problem-Based Learning-Religious STEM (PBL-STEMR) model in this study was conducted through the ADDIE framework, which consists of the stages of analysis, design, development, implementation, and evaluation. Through these stages, a structured learning syntax was produced, namely stimulation, organization, guidance, presentation, and reflection. This syntax was designed not only to facilitate problem-based learning processes but also to systematically integrate the STEM approach and religious reflection. This integration aims to ensure the coherence of cognitive, metacognitive, and affective dimensions within a unified learning process. Such an integrative approach aligns with the demands of 21st-century education, which emphasizes the balance between knowledge, skills, and character development (UNESCO, 2021; OECD, 2023; Darling-Hammond et al., 2020; Fullan et al., 2021). The validation results indicate that the PBL-STEMR model has a very high level of feasibility. The average validation score reached 92.03%, categorized as highly feasible, as presented in Table 1.

Table 1. Validation Results of the PBL–STEMR Model

No	Assessment Component	%	Category
1	Model Expert Validation	87.5	Very good
2	Religious Content Expert Validation	95.8	Very good
3	Practitioner Validation	92.8	Very good
Average		92.03	Very good

The high level of validation demonstrates that the developed model is not only theoretically sound but also practically relevant within the context of madrasah learning. This is important because one of the main challenges in instructional model development is ensuring the alignment between conceptual design and classroom implementation. Therefore, these results indicate that the PBL-STEMR model fulfills the principles of design-based research, which emphasize the alignment between theory, design, and practice (Plomp & Nieveen, 2020; McKenney & Reeves, 2021; Reeves & Lin, 2020; Branch & Kopcha, 2021). Moreover, the involvement of religious content experts in the validation process ensures that the integration of values is not merely symbolic but substantive and contextual (Abdullah et al., 2023; Yusuf et al., 2022).

More specifically, the success of the validation also indicates that the developed syntax structure accommodates the demands of 21st-

century learning, which requires the integration of knowledge, skills, and character. The stimulation stage functions to build curiosity and learning readiness, organization helps students manage information, guidance facilitates exploration, presentation encourages scientific communication, and reflection serves as a space for value internalization and self-evaluation. Thus, this syntax not only supports cognitive achievement but also fosters students' reflective awareness (Ryan & Ryan, 2021; Schön, 2020; Lombardi et al., 2021).

The effectiveness test results show that the PBL-STEMR model has a highly significant effect on students' religious literacy. A comparison between the experimental and control groups is presented in Table 2.

Table 2. Students' Religious Literacy Results

Religious Literacy Aspect	Class	Average Score	Category
Discipline	Experimental Class	97.67	Very Good
	Control Class	79.90	Good
Caring	Experimental Class	97.29	Very Good
	Control Class	80.34	Good

The Mann-Whitney U test results show a significance value of < 0.001, indicating a statistically significant difference between the two groups. The large mean difference suggests that the model has a strong practical effect (high practical significance). These findings confirm that the integration of religious values in science learning has a tangible impact on students' character development (Rahman et al., 2022; Hidayati & Suyadi, 2021; Widodo et al., 2023).

Conceptually, the improvement in religious literacy can be explained through the mechanism of experiential learning embedded in the PBL-STEMR model. Students do not merely receive values declaratively but experience a learning process that connects scientific concepts with religious reflection. This process generates multidimensional engagement, including cognitive, emotional, and spiritual involvement. Such engagement strengthens the internalization of values, as students not only understand but also experience and interpret them meaningfully (Lombardi et al., 2021; Bond et al., 2022).

Furthermore, religious reflection integrated into each stage of learning functions as a self-regulation mechanism. Through reflection, students are encouraged to evaluate their attitudes and behaviors and relate them to relevant religious values. This process enables the transformation from cognitive understanding to moral awareness (Schön, 2020; Ryan & Ryan, 2021; Abdullah et al., 2023). Therefore, religious literacy develops not only at the level of knowledge but also at the level of attitudes and behaviors. These findings indicate that value internalization cannot occur instantly or solely through lecturing but requires a structured reflective process. In this context, religious reflection acts as a bridge between scientific concepts and character development (Yusuf et al., 2022; Rahman et al., 2022).

Regarding metacognitive knowledge, the results show a highly significant improvement in the experimental class compared to the control class, as presented in Table 3.

Table 3. Students' Metacognitive Knowledge Results

No	Class	Score	Category
1	Experimental Class	96.72	Very Good
2	Control Class	78.50	Good

Statistical test results indicate a significance value of <0.001, confirming that the PBL–STEMR model is effective in enhancing students' metacognitive abilities. The substantial mean difference indicates a meaningful improvement. These findings are consistent with previous studies demonstrating that problem-based learning enhances metacognition through active engagement and reflection (Cheng et al., 2021; Schraw et al., 2021; Panadero et al., 2022; Zohar & Barzilai, 2021).

Theoretically, this improvement can be explained through metacognitive scaffolding embedded in the learning syntax. Each stage in the PBL-STEMR model facilitates metacognitive processes, including planning, monitoring, and evaluation (Dignath & Veenman, 2021; Panadero, 2022). Additionally, problem-based learning creates cognitive conflict, which encourages students to think more deeply and reconstruct their understanding (Cheng et al., 2021).

The integration of the STEM approach further enhances the effectiveness of the model. STEM enables students to connect multiple disciplines in solving problems (Bybee, 2021; Li et al., 2023). This approach has been shown to improve critical thinking, creativity, and problem-solving skills (Margot & Kettler, 2022; Becker & Park, 2022; English, 2021). Moreover, the integ-

ration of PBL and STEM creates an authentic and contextual learning environment. Activities such as experiments, discussions, and presentations foster meaningful learning experiences and increase students' intrinsic motivation (Fitriani et al., 2022; Mulyadi et al., 2021). In this study, this motivation is further strengthened by the inclusion of a religious dimension that provides deeper meaning to the learning process.

The novelty of this study lies in the systematic integration of religious reflection into the PBL-STEM framework. This integration demonstrates that combining cognitive, metacognitive, and affective dimensions simultaneously can produce more comprehensive learning outcomes. This finding is aligned with self-regulated learning theory, which highlights the role of intrinsic motivation and values in controlling the learning process (Zimmerman & Schunk, 2021; Panadero, 2022).

From a theoretical perspective, this study expands the framework of PBL and STEM by incorporating the religious dimension as a reinforcement of intrinsic regulation. This is consistent with the direction of 21st-century education, which emphasizes the integration of character education into learning processes (UNESCO, 2021; OECD, 2023; Torres, 2021). Practically, the PBL-STEMR model offers an alternative approach for science learning in madrasahs that not only improves academic achievement but also strengthens students' religious literacy in an integrated manner. The clear syntax of the model facilitates teachers in implementing innovative, meaningful, and contextually relevant learning.

However, this study has limitations. The implementation was limited to a single topic (Earth and the Solar System) and a specific school context. Therefore, further research is needed to test the model across different topics, educational levels, and broader contexts. Future studies may also examine the long-term impact of the model on character development and lifelong learning skills (Li et al., 2023; Fullan et al., 2021).

CONCLUSION

Based on the research results, the PBL-STEMR model on the topic of Earth and the Solar System was successfully developed through the ADDIE stages with the learning syntax consisting of Stimulation, Organization, Guidance, Presentation, and Reflection, which integrates Problem Based Learning, the STEM approach, and religious values in science learning at Madrasah Tsanawiyah (MTs). The results of expert validation and user responses indicate that this model is feasible to be used as a learning guide. Furthermore, its implementation has proven to be effective in improving students' religious literacy and metacognitive knowledge. Therefore, the PBL-STEMR model can serve as an alternative approach to science learning that integrates scientific knowledge and religious values in Madrasah Tsanawiyah (MTs).

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