

Eco-MagneTech Playground: A Prototype for Integrating STEM and Sustainability in Primary Education

Nievesh Nair Surendren¹, Thiyagu Karupaiah¹

¹St. Michael's Institution (SK ST Michael, Ipoh), Malaysia

Corresponding author e-mail: thiyagu.karupaiah@gmail.com

Article History: Received on 3 December 2025, Revised on 26 December 2025,
Published on 3 February 2026

Abstract: A conceptual prototype that integrates STEM learning for primary school students is needed. In this study, a prototype demonstration approach was employed using Eco-MagneTech Playground, involving 32 primary school students aged 12 from a school in the Kinta Utara District. This study employed a qualitative research method. The design and development of the Eco-MagneTech Playground incorporated elements such as solar-powered streetlights, magnetic playground concepts, and a conceptual anti-cosmic radiation jogging track. The findings revealed notable student engagement, and students' understanding of renewable energy and magnetism. Students' questioning skill and evaluative skill provided evidence of emerging critical thinking skills. The Eco-MagneTech Playground is highly potential as an alternative tool to traditional textbook-based science teaching and learning. Unlike traditional classroom-based learning, the Eco-MagneTech Playground promotes active learning and critical thinking among primary school students. It also offers teachers an engaging approach to integrating STEM education through play-based learning environments. Further recommendations for future research were also suggested.

Keywords: Critical Thinking Skill, Hands-on Learning, Primary Science Education, STEM Education

A. Introduction

In today's rapidly evolving world, there is an increasing need to equip primary school students with critical thinking skill, creative thinking skill, environmental awareness, and a strong foundation in science, technology, engineering, and mathematics (STEM) (Ahmad & Siew, 2022; Jamaludin, Fah, Khan, Hoon, & Yee, 2020). Despite this urgency, many conventional primary science instructions often rely heavily on textbook-based (Ridzuwan, Halim, & Mohammad, 2024) and teacher-centred approaches, which have been widely reported to limit students' engagement and opportunities for hands-on STEM learning. (Jamaludin, Fah, Khan, Hoon, & Yee, 2020; Karupaiah & Saleh, 2025a; Karupaiah & Saleh, 2025b). Besides that, resources for learning science through hands-on in primary school is limited (Jamaludin, Fah, Khan, Hoon, & Yee, 2020) specifically in learning magnetics (Samara & Kotsis, 2023).

Additionally, what remains insufficiently explored in primary school is how physically designed, eco-integrated learning environments particularly prototype-based models which can function as structured STEM learning tools in primary science education (Butai, Awang, Ismail, & Eldy, 2021; Ridzuwan, Halim, & Mohammad, 2024). Past studies have shown that experiential and play-based learning environments can enhance students' interest, conceptual understanding, and motivation in science, particularly on magnetism at the primary level (Ahmad & Siew, 2022; Akkaya & Benzer, 2020; Butai, Awang, Ismail, & Eldy, 2021; Ladachart, Radchanet, Phornprasert, & Phothong, 2024; Samara & Kotsis, 2023). Integrating real-world STEM applications within learning spaces has therefore been recognized as a promising strategy to foster early scientific curiosity especially in STEM education (Chang & Yen, 2023; Jamaludin, Fah, Khan, Hoon, & Yee, 2020). As highlighted by Ghazali, Mohamad Ashari, and Ali (2024), effective STEM education for young students must be interactive, developmentally appropriate, and stimulating. However, designing such experiences requires careful planning, as activities can easily become too complex or overly simplistic, potentially failing to meet the students' developmental needs (Karupaiah & Saleh, 2025a; Siew & Ambo, 2018).

To address these challenges and bridge the gap between theory and practice, the Eco-MagneTech Playground was conceptualized and developed as an innovative educational representation tool that integrates STEM learning with sustainability in science classroom. As how suggested in the past studies of scientific models (Chang & Yen, 2023; Dotson, et al., 2020; Klarin, 2016; Sipon, Othman, Rahim, Norwai, & Ahmad, 2021), this model act as a conceptual prototype that encourages active exploration while fostering environmental awareness, offering students an engaging and age-appropriate way to experience STEM in a real-world context specifically in learning environmental sustainability using magnetic principle (Samara & Kotsis, 2023).

On the other hand, Ghavimi, Schuessler, and Pesch (2025) in their work emphasized the importance of evaluating public green spaces holistically through a sustainability lens. Particularly, by incorporating rural and transitional rural-urban areas and recognizing the recreational value of green spaces (GS). Their framework helped to emphasize the importance of inclusive and educational recreational environments that balance both ecological and social functions which need to be strengthened among young students at primary school level. Hence, aligned with this perspective, the Eco-MagneTech Playground serves as a conceptual prototype, enriching eco-friendly recreational model that not only captures students' curiosity but also reinforces the essential STEM concepts, critical and creative thinking skills through interactive and sustainable design similar to what have been emphasized by experts in the field of science education (Amrina, Alfino, Sari, & Hahsa, 2024; Anvarovna & Sayfullayevich, 2024; O'Reilly, Devitt, & Hayes, 2022; Sustiningsih, Utaminingsih, & Santoso, 2021; Üret & Ceylan, 2021). By merging educational value with environmental consciousness, this playground model exemplifies how small-scale

green spaces can be designed to foster learning, well-being, and sustainability, especially in community or school-based settings through design thinking (Aris, Ibrahim, & Halim, 2024; Chang & Yen, 2023). This playground model serves not just as a model for play area, but it also acts as a dynamic learning environment where concepts like renewable energy, magnetism, and simple machines that are related to environmental brought to real-life through interactive elements. This playground model also enhanced the hands-on activity in the classroom and such representation is highly needed in science classroom (Akkaya & Benzer, 2020; Ismail, Fadzil, Saat, & Salleh, 2022; Karupaiah & Saleh, 2025b).

The playground model showcases several innovative features designed to blend play with learning while helping students to keep engaged with the model. One notable aspect in the model is the incorporation of solar-powered streetlights, which familiarize students with the concept of clean energy and its practical applications (PlayPower, Inc., 2021). Complementing this, the playground model is constructed using recycled and anti-rust materials, highlighting the significance of sustainable design and material reuse (Landscape Structures Inc., 2024). In addition, it integrates simple machines powered by magnets, enabling students to observe magnetic forces in action and develop an intuitive understanding of fundamental physical principles such as force, motion, and mechanical advantage (Solis, Curtis, & Hayes-Messinger, 2017).

Adding a touch of imaginative exploration, the playground model features conceptual prototype of an anti-cosmic radiation jogging track, although it's a fictional concept, yet thought-provoking element which was intended to spark curiosity and discussion about space science and cosmic rays among the students. Although the materials used as anti-cosmic radiation concept were not the real anti-cosmic radiation materials, however, only the concepts were included using papers, foils and duct tape into the prototype, in which the students were curious to learn about space science which is related to anti-cosmic radiation. Thus, this inventive component actually serves as a creative gateway, introducing the students to complex scientific concepts which is abstract in an accessible and engaging way (Anvarovna & Sayfullayevich, 2024; Institute of Physics, 2025).

Through this project, students are not only exposed to fundamental scientific and technological concepts but also encouraged to think creatively and critically about how these concepts can be applied in real-world settings (Anvarovna & Sayfullayevich, 2024; O'Reilly, Devitt, & Hayes, 2022; Samara & Kotsis, 2023; Siew & Ambo, 2018). The presentation of science lesson using the model promotes active, inquiry-based learning and serves as an engaging learning tool, inviting students to explore the intersection of STEM and environmental responsibility. By merging playful design with scientific education and sustainable values, the Eco-MagneTech Playground aspires to be a catalyst for STEM engagement and a model for future educational initiatives that prioritize both innovation and ecological invention. The

research questions in this article were 1) How was the process of designing the prototype? 2) How do students respond to the Eco-MagneTech Playground in terms of engagement, understanding of scientific concepts, and inquiry?

B. Methods

This study employs a prototype demonstration approach, facilitated by the first author of this paper, to evaluate the educational potential of the Eco-MagneTech Playground model. The presentation of each concept that is included in the prototype took about twenty-five minutes in front of the students in the classroom. Its primary objective was to gather feedbacks from students, assessing the model's effectiveness in terms of learning by complementing the traditional textbook-based learning through hands-on engagement. By combining prototype demonstration with structured feedback collection, the study also focused on ongoing refinements and improvements to the model's design. As for the participants, in this study, the researchers included 32 students (aged 12) from a local primary school in Kinta Utara District. As per research ethics, each student was assigned with pseudonym to protect their identity.

To achieve the objectives of this study, two main instruments were used, namely, the Eco-MagneTech Playground prototype model and video recordings of the students' responses during completing the Student Feedback Form. These tools were intended to facilitate hands-on STEM learning and to capture the students' cognitive and affective responses to the innovation.

Eco-MagneTech Playground Model

The Eco-MagneTech Playground Model, a scaled-down prototype designed as a supporting teaching representation. This model serves as an interactive stimulus to the students to learn abstract scientific concepts within a relatable, recreational context while not compromising the standard as stated in the Curriculum and Assessment Standard Document (Dokumen Standard Kurikulum dan Pentaksiran, DSKP) (Ministry Of Education, 2018). The prototype integrates four key educational features, which include Solar-Powered Streetlights, this functioning miniature lights powered by solar panels are installed to demonstrate the conversion of solar energy into electrical energy, reinforcing the concept of renewable resources. Besides that, the Recycled Flower Pots were included to promote environmental awareness, the model utilizes components crafted from recycled and anti-rust materials, visually demonstrating sustainable design and waste reduction practices. As for the magnetic concepts, Magnetic Playground prototype was included as the core mechanical features of the playground (such as swings or seesaws) are actuated using magnets. This allows students to physically manipulate and observe magnetic attraction and repulsion, providing a hands-on experience with forces and simple machines. Additionally, to enhance the creative thinking skill among students, the Anti-Cosmic

Radiation Jogging Track conceptual prototype was added. This conceptual feature introduced to spark imagination and higher-order thinking especially in science while strengthening STEM elements among students. While theoretical, this track is designed to provoke curiosity about space science, atmospheric protection, and cosmic rays, encouraging students to ask questions beyond standard curriculum limits. Figure 1 in this article shall explain in detail about the model built, the Eco-MagneTech Playground.

Model built: Eco-MagneTech Playground

Figure 1 is a detailed prototype designed to showcase the integration of advanced engineering with ecological responsibility. This prototype model moves beyond theoretical concepts, illustrating how the robust magnetic concepts applied to teach the students, while. Furthermore, the materials used to build the model highlights the synergy of sustainable materials, such as recycled surfacing, with active renewable power systems, demonstrating that a public park can be a resilient, low-maintenance, and energy-positive structure that simultaneously educates its users while preserving the environment.

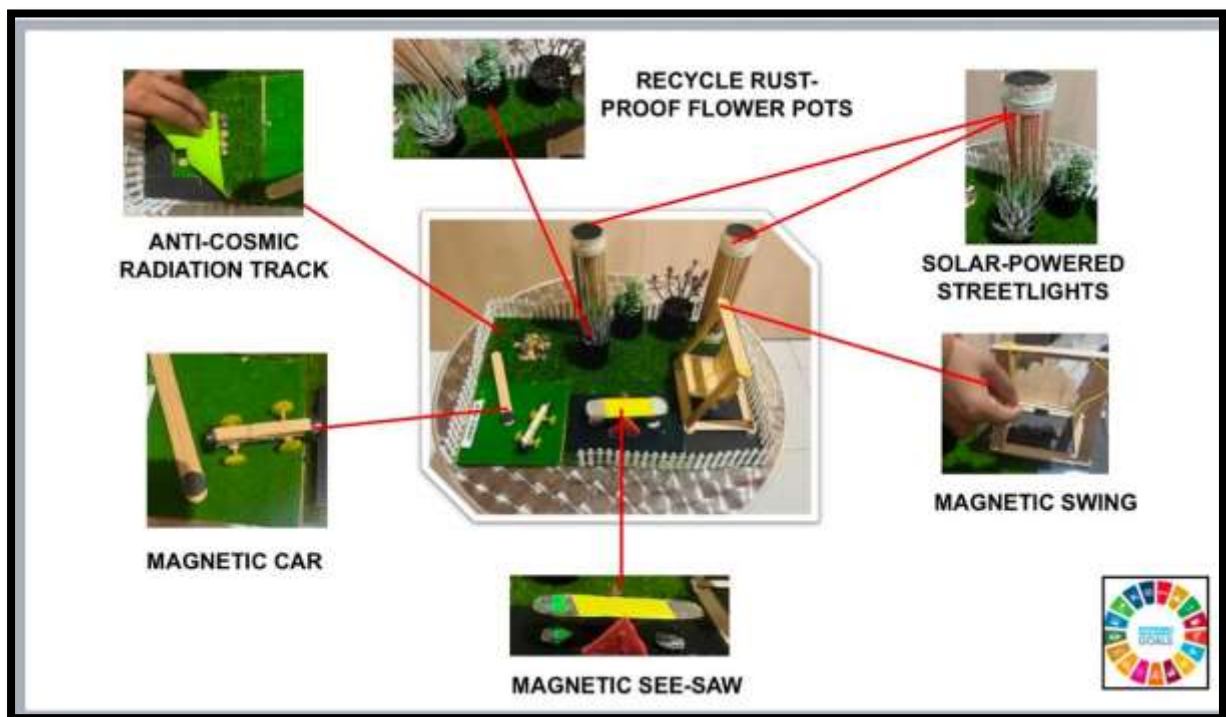


Figure 1. Prototype Model of a Sustainable Playground Featuring Magnetic and Eco-Friendly Components

The prototype usage as representation in the classroom

The following sections explain how the prototype were used in the classroom.

Introduction (5 minutes)

The facilitator student briefly explains the purpose of the mini playground model and how it relates to scientific and environmental concepts typically taught through textbooks. The goal is to set expectations and link the demonstration to prior knowledge among students.

Demonstration & Exploration (15–20 minutes)

The researcher (first author) presents the model in action, highlighting and explaining the following key features of the conceptual prototype:

1. Solar-Powered Streetlights: Demonstrates renewable energy and sustainability concepts.
2. Recycled Rust-Proof Flower Pots: Shows recycling and eco-friendly material usage.
3. Magnetic Playground Activities: Includes magnetic see-saws, swings, and cars to teach principles of magnetism, motion, and mechanics.
4. Conceptual Anti-Cosmic Radiation Jogging Track: Promotes physical activity while educating about cosmic radiation and health protection.

Students observe and interact with the model, where possible, to engage with the concepts hands-on.

Feedback Session (10–15 minutes)

After the exploration session, the students verbally respond to structured feedback, which assesses:

1. Overall enjoyment and engagement.
2. Perceived difficulty of understanding and interacting with the model.
3. Key learning takeaways expressed in their own words.
4. Favorite parts of the playground.
5. Curious questioning and suggestions for improvement or additions.

Prototype Development

To ensure the effectiveness and practicality of the proposed model, a prototype was developed and tested as part of the methodology, which serves multiple purposes. The process is illustrated in the Figure 2 below explains the process of design and development of the prototype.

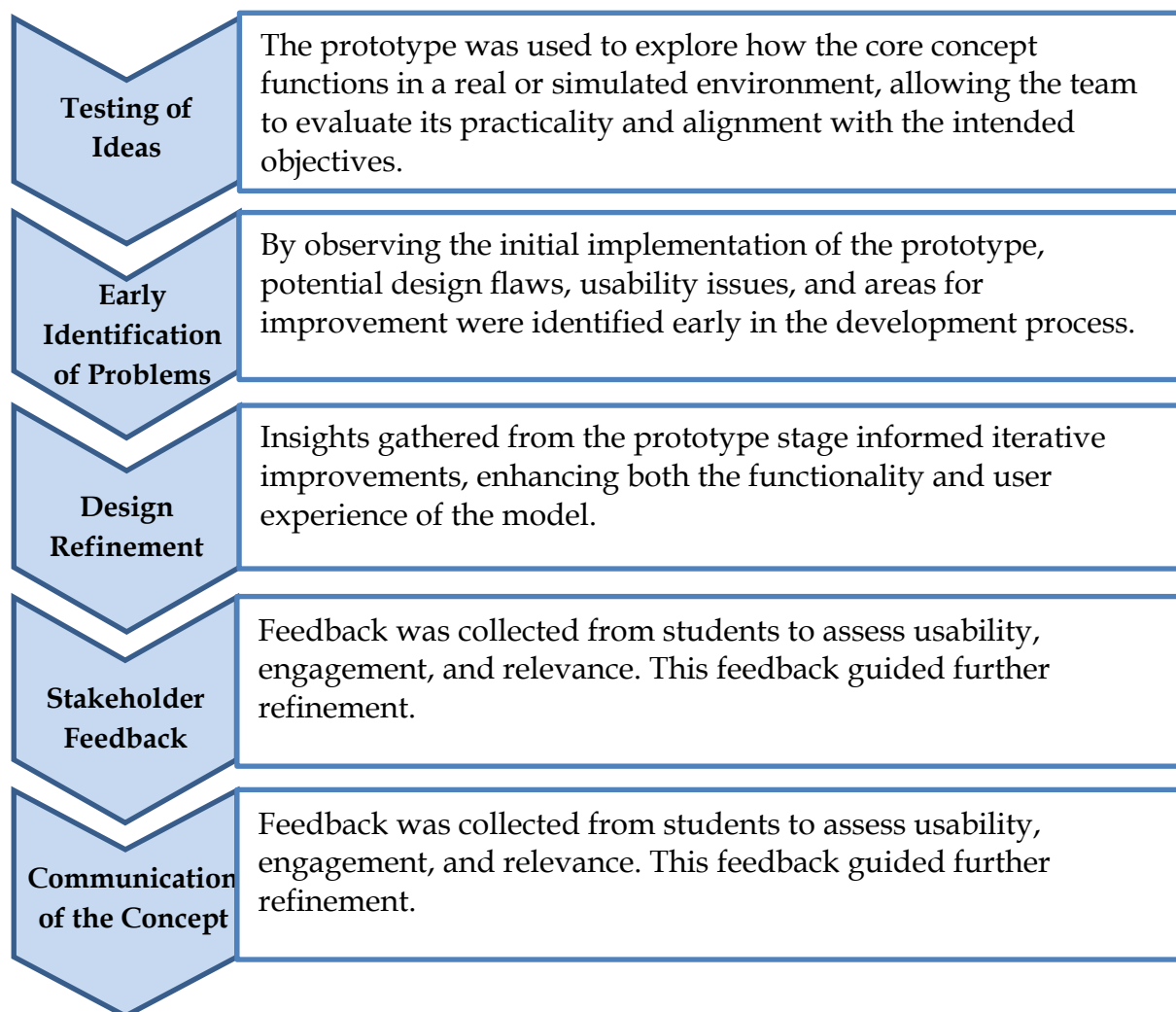


Figure 2: Iterative Design Cycle Guided by Prototype Testing

This prototyping approach enabled a more effective and user-informed design process, increasing the likelihood of the model's success in real-world application.

Student Feedback Form

This instrument acts as a simple self-assessment tool designed to be age-appropriate for primary school students. The feedback form collects data across several dimensions which include affective engagement as this item measured the students' level of enjoyment and interest while interacting with the model. Also, for learning outcomes, questions assessing what the students felt they learnt regarding magnetism and sustainability were elicited. Students were also encouraged to provide preferences and suggestions by including open-ended sections requiring students to provide feedbacks of what have they learnt by using the playground model and offer suggestions for improvement. This qualitative data is crucial for addressing the study's objective to explore students' engagement, understanding, and inquiry

responses when interacting with the Eco-MagneTech Playground.

Data Collection and Analysis

Data were collected through structured verbal feedback, questions and open-ended responses following students' interaction with the Eco-MagneTech Playground prototype. Students' responses focused on their engagement, understanding of scientific concepts, inquiry responses, and questions raised during the demonstration sessions. During the verbal responses and questions, video recordings were done.

The qualitative data were analyzed using thematic analysis. All the students' responses were carefully read and the video recordings were carefully transcribed verbatim using manual transcription. The transcribed scripts were read repeatedly to ensure familiarization with the data. Initial codes were generated inductively based on recurring ideas and patterns observed in the students' responses. These codes were then organized into broader themes that reflected students' engagement, conceptual understanding, curiosity, and inquiry responses that elaborate the perceived learning value of the prototype.

To enhance the trustworthiness of the analysis, themes were compared across multiple responses to ensure consistency, and representative excerpts were used to support interpretations. The analysis focused on identifying dominant trends rather than individual responses, aligning with the exploratory nature of the study. The resulting themes informed the evaluation of the prototype's educational effectiveness and guided recommendations for further design refinement.

Ethical Considerations

Although the concepts introduced in this study are part of learning of scientific concepts in science classroom, the participation was however set as voluntary, and fortunately all the students took part in the learning process and their feedback were only used for the purpose of this study including but not limited to model refinement.

C. Results and Discussion

Based on the thematic analysis of students' feedback and observed interactions with the Eco-MagneTech Playground prototype, four dominant themes emerged. These themes reflect students' affective, cognitive, and inquiry-based responses to the prototype-based STEM learning experience.

Theme 1: High Engagement through Hands-On and Play-Based Interaction

The first theme highlights students' strong engagement when interacting with the Eco-MagneTech Playground prototype. Similar to past studies by Akkaya and Benzer,

(2020) and Samara and Kotsis, (2023), the hands-on and play-based nature of the model effectively captured students' attention and sustained their interest throughout the session. In relation to students' engagement discussed by Hernández, (2012), Linnansaari, Viljaranta, Lavonen, Schneider, and Salmela-Aro, (2015) and Tiong and Bakar, (2022), students' verbal expressions and observable behaviours indicate both affective excitement and active involvement, particularly when they were able to manipulate the magnetic playground components directly.

For instance, a participant named Vicky expressed surprise and interest upon observing the magnetic mechanism in action, stating, "hey, interesting to see the 'stroller' can be pushed using magnets." This response reflects immediate curiosity and cognitive engagement, as the student recognised an unfamiliar application of magnetism within a playful context. The use of the term "interesting" suggests positive emotional engagement, which is a key indicator of sustained attention in play-based learning environments (Linnansaari et al, 2015; Samara & Kotsis, 2023).

Similarly, Ali demonstrated reflective engagement by connecting prior knowledge with new learning, remarking, "I knew that magnets are useful. But I did not expect it can be so useful to make a playground." This statement indicates that the prototype challenged the student's existing understanding and expanded their perception of how scientific concepts can be applied in real-world and recreational settings, similarly to what other past researchers have mentioned in their studies (Ahmad & Siew, 2022; Samara & Kotsis, 2023; Tan, Yangco, & Que, 2020). Such reflections align with constructivist learning principles, where new experiences prompt learners to restructure and extend their prior knowledge (Kalpana, 2014).

In addition, Zhen's request to interact with the magnetic seesaw further illustrates active participation and enthusiasm: "Can I try the see saw? I have seen a spring see saw. This is my first-time experience that magnets can help us play see saw." This excerpt highlights the student's eagerness to engage physically with the model and their ability to compare the magnetic seesaw with conventional playground equipment. The comparison demonstrates early analytical thinking and reinforces the role of hands-on exploration in supporting meaningful learning experiences (Yopp, 2006).

Collectively, these excerpts provide clear evidence that the physical and interactive design of the Eco-MagneTech Playground fostered high levels of engagement through play-based interaction. Students were not passive observers but active participants who expressed curiosity, excitement, and a willingness to explore. This finding supports some findings as reported in the past studies that the effectiveness of tangible, experiential learning environments is beneficial in promoting engagement and interest in primary science education (Butai, Awang, Ismail, & Eldy, 2021; Linnansaari et al, 2015; Samara & Kotsis, 2023).

Theme 2: Improved Conceptual Understanding of STEM and Sustainability Concepts

The second theme reflects students' emerging understanding of core STEM and sustainability concepts presented through the Eco-MagneTech Playground prototype. Students demonstrated the ability to interpret scientific ideas related to renewable energy and sustainable design, indicating that the visual and tangible features of the model supported meaningful conceptual learning. This ability compliments the past studies in science education that focus on STEM understandings towards sustainability (Dotson, et al., 2020).

Nathanial's response illustrates students' understanding of the practical application of solar energy in everyday contexts. He remarked, "The solar light in the park looks interesting. This model is promising and definitely will be useful for us to use the playground at night." He further connected the use of solar-powered lighting to social and environmental realities, noting that "since most of our parents are busy working in the day time, we can go to the playground in the late evening." This response demonstrates that the student not only understood the function of solar-powered streetlights but was also able to relate renewable energy use to real-life needs and social practices, reflecting meaningful and contextualized learning.

Similarly, another student, Foong extended the sustainability concept by proposing an additional application of solar energy storage, stating, "I would like to suggest if you can put a charging point for our personal devices using solar energy storage." This suggestion reflects a deeper level of conceptual understanding, as the student recognized the potential of energy storage and secondary usage of renewable energy beyond the immediate function demonstrated in the prototype. The ability to propose enhancements indicates that the student was able to transfer learned concepts to new contexts, a key indicator of conceptual understanding in STEM education (Combs, Cennamo, & Newbill, 2009; Dalton, Morocco, Tivnan, & Mead, 1997; Tan, Yangco, & Que, 2020).

Darry's comment, "this model needs a lot more interesting thing and cannot be only using magnets and solar panels," provides further insight into students' cognitive engagement. Rather than indicating a lack of understanding, this response suggests that the student perceived the prototype as a platform with potential for expansion. The comment reflects an evaluative stance, where the student critically considered the range of scientific elements presented and implicitly called for greater diversity of STEM features. In the past research, Antonio and Prudente, (2024) have discussed on the effects of inquiry-based approach on students' higher order thinking skill which is similar to the present study in which this evaluative thinking indicates that students were not merely accepting the model at face value but were actively assessing its design and educational value.

Overall, these student responses indicate that the Eco-MagneTech Playground supported students' conceptual understanding by making STEM and sustainability concepts visible, functional, and relevant to real-world contexts. The prototype enabled students to move beyond basic recognition of scientific features toward application, evaluation, and idea generation, demonstrating its effectiveness in making science content accessible and meaningful for primary school learners.

Theme 3: Curiosity-Driven Inquiry and Emerging Critical Thinking

A prominent theme that emerged from the analysis was students' curiosity-driven inquiry, particularly in relation to the magnetic playground components. Students actively questioned the implications, limitations, and potential risks associated with the use of magnets, demonstrating early scientific reasoning and evaluative thinking beyond surface-level observation. This pattern of questioning indicates the emergence of critical thinking skills, as students engaged with underlying physical principles and real-world considerations (Combs, Cennamo, & Newbill, 2009; Sipon, Othman, Rahim, Norway, & Ahmad, 2021).

A participant in this study, Samson, whose response illustrates analytical and anticipatory reasoning when he questioned the broader environmental impact of magnetic playground equipment, stating, "How if most of the play tools are made of magnets and the surrounding cars are magnetic objects? Would not it be causing serious accidents?" This excerpt reflects the student's ability to extend scientific thinking beyond the immediate prototype to consider safety, interaction with surrounding objects, and unintended consequences. Such reasoning demonstrates an emerging understanding of cause-and-effect relationships and risk evaluation, which are key components of critical thinking in science education (Gencer & Dogan, 2020).

Similarly, Steve's concern highlights health-related inquiry and ethical awareness. He asked, "Is magnetism really good for our health? How if a parent or guardian has a pacemaker?" This question shows that the student was not only considering the scientific properties of magnets but also their potential biological and medical implications. The ability to connect scientific concepts with human health and safety indicates higher-order thinking and reflects inquiry-based learning, where students critically examine the applicability and limitations of scientific innovations in real-life contexts (Amrina, Alfino, Sari, & Hahsa, 2024; Gencer & Dogan, 2020; Tan, Yangco, & Que, 2020).

On the other hand, Arjun's statement, "we should not bring our mobile phones, coins and keys to the playground," demonstrates the application of scientific reasoning to practical decision-making. This response suggests that the student inferred potential interactions between magnets and everyday objects and translated this understanding into a precautionary rule. Such behaviour as discussed by past researcher Ladachart et al, (2024) reflects that early hypothesis formation and application of scientific

knowledge to personal and communal safety practices enable students to think beyond the scientific contents.

Collectively, these excerpts indicate that the Eco-MagneTech Playground functioned not merely as a demonstration model but as a catalyst for inquiry-based learning as also emphasized in the past research on inquiry-based learning (Antonio & Prudente, 2024; Dalton, Morocco, Tivnan, & Mead, 1997). Students moved from observing magnetic effects to questioning safety, health implications, and environmental interactions, illustrating the development of emerging critical thinking skills. This finding supports the role of inquiry-oriented, hands-on learning environments in fostering analytical reasoning and responsible scientific thinking among primary school students similar to what stated by Combs, Cennamo, and Newbill, (2009), Gencer and Dogan, (2020) and Kelley and Knowles, (2016).

Theme 4: Imaginative Thinking and Conceptual Challenge

The fourth theme highlights students' imaginative thinking which is related with creative thinking skill (Anvarovna & Sayfullayevich, 2024) especially with the conceptual anti-cosmic radiation jogging track, as well as the cognitive challenges associated with understanding abstract scientific ideas (Klarin, 2016). This conceptual feature has prompted speculative thinking among the students about the space science, environmental protection, and human health, while simultaneously revealing the limits of students' prior knowledge (Klarin, 2016) and the need for instructional scaffolding.

In this study, Steve's question, "Is the anti-cosmic also possible to shield us from UV light?", illustrates how the prototype stimulated imaginative reasoning and conceptual transfer. By relating cosmic radiation to ultraviolet (UV) radiation, the student attempted to connect unfamiliar scientific ideas with more familiar concepts. Having curiosity to learn more, this form of analogical thinking reflects the creative engagement and an effort to construct meaning through comparison, which is a key characteristic of constructivist learning. Having the effort to construct meaning from what was learnt proves that student-centered learning ensures better understanding on science concepts (Kalpana, 2014).

Additionally, another student, Azfa's responses further demonstrate both curiosity and conceptual difficulty. The statement, "Actually, I don't understand the anti-cosmic radiation. But if it is good for our health, then we should consider it," indicates awareness of limited understanding while still engaging with the idea's perceived value. This metacognitive awareness by recognizing what is not yet understood suggests reflective thinking (Amrina, Alfino, Sari, & Hahsa, 2024). Azfa's additional comment, "We also should think on making our playground safe from meteors," reflects imaginative extension (Anvarovna & Sayfullayevich, 2024) beyond the original concept, highlighting how the feature encouraged speculative thinking about

space-related hazards, even if these ideas exceeded the intended scientific scope.

Similarly, Dex's remark, "I need to read more on this type of playground because seriously speaking, I don't really know what anti-cosmic radiation is," provides clear evidence of conceptual challenge. At the same time, it demonstrates learning motivation, as the student recognized a knowledge gap and expressed an intention to seek further information (Haron, Kamaruddin, Harun, Abas, & Salim, 2017; Potvin & Hasni, 2014; Xie & Reider, 2014). This response indicates that although the concept was difficult, it successfully triggered curiosity and self-directed learning which have also been widely deliberated in past studies (Potvin & Hasni, 2014; Xie & Reider, 2014).

Collectively, these excerpts reveal that the playground model especially the conceptual anti-cosmic radiation jogging track functioned as a double-edged pedagogical element, for the learning purpose and curiosity spark. While it stimulated imagination and interest in advanced scientific ideas, it also demanded higher levels of thinking than other features of the prototype. Hence, this finding emphasizes the importance of aligning conceptual complexity with students' developmental levels and providing appropriate scaffolding (Vasileva & Balyasnikova, 2019; Vygotsky, 1978) when introducing abstract, hypothetical and speculative scientific concepts in primary science education.

D. Conclusions

The Eco-MagneTech Playground prototype that was used in this study is highly potential as an innovative instructional tool for integrating STEM education and environmental sustainability in primary science learning. Through the design and implementation of the prototype, the results of the study highlight the need for more engaging and hands-on learning approach for students. Teachers should apply hands-on learning approach as an alternative method to the traditional textbook-based teaching and learning. It is notable through the students' engagement that the playground model was able to improve their conceptual understanding, increase the curiosity-driven inquiry, and creative thinking. The hands-on and play-based nature of the prototype have also enhanced the students' interest, while its features have supported meaningful connections between abstract scientific concepts and real-world applications. Importantly, the students' questioning skill and ability to evaluate responses indicate the emergence of critical thinking skills, which is crucial for decision making in STEM fields. This highlights the role of prototype as a supporting tool for inquiry-based learning rather than just a demonstration model. From a pedagogical perspective, the study supports constructivist and inquiry-based learning approaches by encouraging active knowledge construction among primary school students. At the same time, the findings also emphasize the need for suitable scaffolding especially when introducing new and abstract scientific concepts, that require higher order thinking skills. Despite being involving a small sample within a single school context, this study provides preliminary evidence that the Eco-

MagneTech Playground can complement the traditional teaching and learning in science classrooms. As for further recommendation, future researchers may consider a larger sample and comparative studies to evaluate the effectiveness of conceptual prototypes in science classrooms. Overall, the Eco-MagneTech Playground contributes a promising proof-of-concept for integrating STEM, sustainability, and play-based learning, and offers valuable insights for teachers and curriculum development division to create meaningful learning approach in primary education.

E. Acknowledgement

The authors would like to thank the students who have actively participated in this study.

References

- Ahmad, J., & Siew, N. M. (2022). An entrepreneurial science thinking module based on the socioscientific issues approach with thinking wheel map for primary school students in STEM education. *Problems of Education in The 21st Century*, 80(1), 30-50. <https://doi.org/10.33225/pec/22.80.30>
- Akkaya, M. M., & Benzer, S. (2020). The effect of STEM practices on academic achievement and attitudes of sixth grade students: An application on the unit of force and motion. *Malaysian Online Journal of Educational Sciences*, 8(2), 36-47.
- Amrina, Z., Alfino, J., Sari, S. G., & Hahsa, N. (2024). Analysis of critical thinking, creative thinking and problem solving skills on elementary school students: a descriptive correlation study. *Jurnal Pendidikan MIPA*, 25(2), 784-791. <https://doi.org/10.23960/jpmipa/v25i2.pp784-791>
- Antonio, R. P., & Prudente, M. S. (2024). Effects of Inquiry-based approaches on students' higher-order thinking skills in science: A meta-analysis. *International Journal of Education in Mathematics, Science, and Technology*, 12(1), 251-281. <https://doi.org/10.46328/ijemst.3216>
- Anvarovna, A. M., & Sayfullayevich, M. A. (2024). Developing creative thinking skills among primary school students. *Nanotechnology Perceptions*, 20(2), 224-231.
- Aris, N. M., Ibrahim, N. H., & Halim, N. D. (2024). Beyond the classroom: Expert teachers' perspectives on developing innovation competencies through design thinking practices. *Jurnal Pendidikan Bitara UPSI*, 17(1), 72-81. <https://doi.org/10.37134/bitara.vol17.1.7.2024>
- Butai, S. N., Awang, H., Ismail, I. H., & Eldy, E. F. (2021). Effectiveness of PBL-STEM module in physics on students' interest: A preliminary finding of implementation amongst students in rural areas of Sabah, Malaysia. *Transactions on Science and Technology*, 380-387.
- Chang, C.-C., & Yen, W.-H. (2023). The role of learning style in engineering design thinking via project-based STEM course. *Asia Pacific Journal of Education*, 43(4), 1125-1143. <https://doi.org/10.1080/02188791.2021.1957776>
- Combs, L. B., Cennamo, K. S., & Newbill, P. L. (2009). Developing critical and creative

- thinkers: Toward a conceptual model of creative and critical thinking processes. *Educational Technology*, 49(5), 3-14.
- Dalton, B., Morocco, C. C., Tivnan, T., & Mead, P. L. (1997). Supported inquiry science: Teaching for conceptual change in urban and suburban science classrooms. *Journal Of Learning Disabilities*, 30(6), 670-684. <https://doi.org/10.1177/002221949703000611>
- Dotson, M. E., Alvarez, V., Tackett, M., Asturias, G., Leon, I., & Ramanujam, N. (2020). Design thinking-based STEM learning: Preliminary results on achieving scale and sustainability through the IGNITE model. *Curriculum, Instruction, And Pedagogy*, 5, 1-10. <https://doi.org/10.3389/feduc.2020.00014>
- Gencer, A. S., & Dogan, H. (2020). The assessment of the fifth-grade students' science critical thinking skills through design-based STEM education. *International Journal of Assessment Tools in Education*, 7(4), 690-714. <https://doi.org/10.21449/ijate.744640>
- Ghavimi, A., Schuessler, F., & Pesch, R. (2025). A framework to evaluate public green spaces with an emphasis on recreational values for sustainable urban and rural areas: A systematic review and content analysis. *Heliyon*, 11(2), e41553. <https://doi.org/10.1016/j.heliyon.2024.e41553>
- Ghazali, A., Mohamad Ashari, Z., & Ali, A. (2024). The importance of STEM education in 21st-century learning from the perspectives of pre-service kindergarten teachers: A survey study. *1st Global Waqf International Conference 2024*
- Haron, H., Kamaruddin, S. A., Harun, H., Abas, H., & Salim, K. R. (2017). Science, Technology, Engineering and Mathematics initiatives at rural schools and its impact on learning motivation. *Journal of Physics*, 1-10. <https://doi.org/10.1088/1742-6596%2F1174%2F1%2F012002>
- Hernández, R. (2012). Collaborative learning: Increasing students' engagement outside the classroom. *US-China Education Review*, 804-812.
- Institute of Physics. (2025). Cosmic rays. <https://www.iop.org/explore-physics/physics-around-you/understanding-surroundings/cosmic-rays>
- Ismail, M. H., Fadzil, H. M., Saat, R. M., & Salleh, M. F. (2022). A Needs analysis study for the preparation of integrated STEM instructional practices through scientist-teacher-student partnership (STSP). *ASM Science Journal*, 17, 1-16. <https://doi.org/10.32802/asmscj.2022.1112>
- Jamaludin, J., Fah, L. Y., Khan, C. G., Hoon, K. C., & Yee, A. L. (2020). Development of STEM teaching module for rural primary schools in Sabah: Need analysis with justification and key features. *Learning Science and Mathematics*, 15(1), 30-39.
- Kalpana, T. (2014). A Constructivist perspective on teaching and learning: A conceptual framework. *International Research Journal of Social Sciences*, 3, 27-29.
- Karupaiah, T., & Saleh, S. (2025a). Challenges in integrating design thinking and resources utilisation in science classrooms: A qualitative exploration of the Malaysian classrooms. *International Journal of Advanced Research in Education and Society*, 7(2), 37-49. <https://doi.org/10.55057/ijares.2025.7.2.5>
- Karupaiah, T., & Saleh, S. (2025b). Malaysian science teachers' needs for a design thinking-based STEM module in year four physical science. *Jurnal Pendidikan*

- Sains Dan Matematik Malaysia, 15(1), 111-128.
<https://doi.org/10.37134/jpsmm.vol15.1.9.2025>
- Kelley, T. R., & Knowles, J. G. (2016). A conceptual framework for integrated STEM education. *International Journal of STEM Education*, 3(11), 1-11.
<https://doi.org/10.1186/s40594-016-0046-z>
- Klarin, M. (2016). Conceptual challenges in understanding innovative education in organizational context. *International Journal of Cognitive Research in Science, Engineering and Education*, 4(1), 67-72.
<https://doi.org/10.5937/IJCRSEE1601067K>
- Ladachart, L., Radchanet, V., Phornprasert, W., & Phothong, W. (2024). Influence of different approaches to design-based learning on eighth grade students' science content learning and STEM identity. *Pedagogies: An International Journal*, 19(2), 300-325. <https://doi.org/10.1080/1554480x.2023.2230961>
- Landscape Structures Inc. (2024). Materials matter: Sustainable and durable playground components. Retrieved November 10, 2025, from <https://www.playlsi.com/en/playground-planning-tools/design-philosophy/materials-matter/materials-matter/>
- Linnansaari, J., Viljaranta, J., Lavonen, J., Schneider, B., & Salmela-Aro, K. (2015). Finnish students' engagement in science lessons. *Nordic Studies in Science Education*, 11(2), 192-206. <https://doi.org/10.5617/nordina.2047>
- Ministry Of Education. (2018). Dokumen Standard Kurikulum dan Pentaksiran Sains Tahun 4. Kurikulum Standard Sekolah Rendah. Bahagian Pembangunan Kurikulum.
- O'Reilly, C., Devitt, A., & Hayes, N. (2022). Critical thinking in the preschool classroom - A systematic literature review. *Thinking Skills and Creativity*, 46, 1-20. <https://doi.org/10.1016/j.tsc.2022.101110>
- PlayPower, Inc. (2021, September 21). PlayPower introduces solar-powered PlaySoleil® lighting for playgrounds at NRPA annual conference. Retrieved November 10, 2025, from <https://playpower.com/playpower-introduces-solar-powered-playsoleil-lighting-for-playgrounds-at-nrpa-annual-conference/>
- Potvin, P., & Hasni, A. (2014). Interest, motivation and attitude towards science and technology at K-12 levels: a systematic review of 12 years of educational research. *Studies in Science Education*, 50(1), 85-129. <http://dx.doi.org/10.1080/03057267.2014.881626>
- Ridzuwan, A. Z., Halim, L., & Mohammad, W. M. (2024). A Conceptual framework of teacher and student strategies in the use of science textbooks through a systematic literature review. *Jurnal Pendidikan Sains Dan Matematik Malaysia*, 14(2), 1-20. <https://doi.org/10.37134/jpsmm.vol14.2.1.2024>
- Samara, V., & Kotsis, K. T. (2023). A teaching intervention for magnetism using STEM in kindergarten. *International Journal of Professional Development, Learners and Learning*, 5(2), 1-8. <https://doi.org/10.30935/ijpdll/13667>
- Siew, N. M., & Ambo, N. (2018). Development and evaluation of an integrated project-based and stem teaching and learning module on enhancing scientific creativity among fifth graders. *Journal of Baltic Science Education*, 17(6), 1017-1033.

- <https://dx.doi.org/10.33225/jbse/18.17.1017>
- Sipon, S., Othman, M. Z., Rahim, F., Norwai, N., & Ahmad, R. (2021). The effects of integrating STEM education through STEM module: Towards a skilled workforce and consistent learning society. *E-Prosiding Seminar Antarabangsa Islam dan Sains 2021* (p. 940=953). Negeri Sembilan: Universiti Sains Islam Malaysia.
- Solis, S. L., Curtis, K. N., & Hayes-Messinger, A. (2017). Children's exploration of physical phenomena during object play. *Journal of Research in Childhood Education*, 31(1), 122-140.
- Sustiningsih, Utaminingsih, S., & Santoso. (2021). Development of science teaching materials based on STEM: A needs analysis. *Journal of Physics: Conference Series*, 1-7. <https://doi.org/10.1088/1742-6596/1823/1/012081>
- Tan, R. M., Yangco, R. T., & Que, E. N. (2020). Students' conceptual understanding and science process skills in an inquiry-based flipped classroom environment. *Malaysian Journal of Learning and Instruction*, 17(1), 159-184. <https://doi.org/10.32890/mjli2020.17.1.7>
- Tiong, G. H., & Bakar, A. Y. (2022). The engagement of critical and creative thinking activities in the teaching and learning process. *ASEAN Journal of Educational Research and Technology*, 1(2), 139-146.
- Üret, A., & Ceylan, R. (2021). Exploring the effectiveness of STEM education on the creativity of 5-year-old kindergarten children. *European Early Childhood Education Research Journal*, 29(6), 842-855. <https://doi.org/10.1080/1350293X.2021.1913204>
- Vasileva, O., & Balyasnikova, N. (2019). (Re)Introducing Vygotsky's thought: From historical overview to contemporary psychology. *Front. Psychol.*, 10, 1-15. <https://doi.org/10.3389/fpsyg.2019.01515>
- Vygotsky, L. S. (1978). *Mind and Society: The Development of Higher Psychological Processes*. Cambridge: Harvard University Press.
- Xie, Y., & Reider, D. (2014, June). Integration of innovative technologies for enhancing students' motivation for science learning and career. *Journal of Science Education and Technology*, 23(3), 370-380. <https://doi.org/10.1007/s10956-013-9469-1>
- Yopp, R. H. (2006). Enhancing hands-on science experiences with informational texts: Learning about pine cones. *Science Activities: Classroom Projects and Curriculum Ideas*, 43(3), 31-34. <https://doi.org/10.3200/SATS.43.3.31-34>