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Model-Eliciting Activities-Integrated Metaverse: Elevating Mathematical Connections and Learning Achievement for Grade 6 Students

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***Abstract*—This pilot study addresses the limitations of passive digital visualization in mathematics by developing and initially validating a learning activity package that integrates Model-Eliciting Activities (MEAs) with Metaverse technology. Using a Research and Development (R&D) framework, the study aimed to assess the feasibility of enhancing mathematical connection skills and learning achievement among Grade 6 students. The Metaverse integration provided an immersive environment to facilitate real-world problem-solving inherent in MEAs. The package was implemented with a purposively selected small group of nine students ($N = 9$) in Southern Thailand. Instruments included the developed learning package, a mathematical connection skills assessment, and a learning achievement test. Findings revealed that: (1) the Metaverse-integrated MEA package achieved an efficiency of 83.48/83.33 (E1/E2); (2) students' mathematical connection skills and academic achievement scores were significantly higher after learning ($p < 0.05$); and (3) a high Normalized Gain (N-Gain = 0.70). These preliminary results suggest the potential of immersive Metaverse environments to reduce abstraction barriers by providing a concrete scaffold for model construction. This study provides a validated prototype for future large-scale research while highlighting the need for controlled trials to isolate technological novelty effects.**

***Keywords*—model-eliciting activities, metaverse, mathematical connection skills, experiential learning, pilot study**

I. INTRODUCTION

Mathematics plays an important role in bringing up creativity, logical reasoning, and systematic thinking, skills that are essential for problem-solving in a rapidly changing world [1, 2]. It serves as a foundational tool for scientific advancement and daily decision-making. Modern education systems increasingly prioritize learner-centered approaches to develop these competencies [3, 4]. However, mathematics education globally faces a persistent challenge: the disconnect between abstract mathematical concepts and their real-world applications [5, 6]. International assessments, such as the Program for International Student Assessment (PISA), consistently highlight that students struggle to transfer theoretical knowledge to solve authentic problems [7]. While this is a global issue, it's especially pressing in Thailand, where developing innovative teaching methods to close this gap remains a national priority [1, 8].

In Thailand, the evaluation of mathematics education quality has reflected these challenges. National test scores (O-Net) for primary school students have shown a concerning decline, with mathematics averages dropping to 29.96 out of 100 in 2023 [9]. These low scores aren't just numbers; they also reveal a fundamental challenge. Students often struggle to connect abstract math concepts with practical applications. Effective teaching approaches are necessary to do more than just drill formulas if we want to eliminate this gap and meet our curriculum objectives [10, 11]. The curriculum itself presents another obstacle. When content is taught in disconnected segments, students find it difficult to see how different mathematical concepts relate to each other [2]. This is why mathematical processes should be focused, not just isolated skills, so that students can utilize what they learn in meaningful and lasting ways [1, 8].

Mathematical connection skills are critical in addressing this fragmentation [12]. These skills allow students to meaningfully link mathematical principles meaningfully to solve problems or understand complex concepts in new situations [6, 13]. Categorized into three types of linking knowledge within mathematics, connecting mathematics to other fields, and linking mathematics to real-life situations these skills enable students to understand content more deeply [14, 15]. Developing these connection skills is not merely about rote memorization but about integrating math with other subjects to demonstrate its real-world value [2, 8].

To raise these skills, learning activity packages serve as systematic tools for knowledge delivery [16]. They provide a structured approach to practical tasks, making it easier for teachers to support different learners and manage limited resources [17, 18]. However, research on developing mathematical connection skills remains limited, particularly regarding how innovative technologies can support real-world mathematical modeling in primary education [4, 19]. Traditional teaching often focuses on procedures, making it hard for students to see how math relates to everyday life [12].

Model-Eliciting Activities (MEAs) help students develop real-world problem-solving skills [5, 20], but the standard text-based format can be too abstract for primary students. This presents a unique opportunity for Metaverse, which can situate mathematical tasks in experiential, 3D virtual contexts that simulate authentic problem situations [21–23]. The Metaverse serves as a bridge between students and the real-world contexts that MEA requires. It turns abstract math problems into experiences students can actually explore and manipulate. While Model-Eliciting Activities (MEAs) have demonstrated promise in developing modeling competencies, establishing authentic contexts for primary learners remains a challenge. The Metaverse offers the immersive potential to bridge this gap; however, it is not a standalone solution.

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Without thoughtful pedagogical integration, such environments risk prioritizing technological novelty over substantive learning. Although recent studies have explored digital tools in mathematics education [21, 24], many prioritize passive visualization, reducing learners to mere observers. This study addresses this critical gap by synergizing the cognitive framework of MEAs with the interactive affordances of the Metaverse. Transcending the use of virtual environments as mere presentation media, this research introduces an instructional intervention designed to facilitate active model construction. By enabling students to build, test, and refine mathematical models within a 3D space, this approach aims to enhance both mathematical connection skills and deep conceptual understanding [16].

II. THEORETICAL FRAMEWORK

In this research, the Metaverse is defined as an immersive 3D environment where students interact as avatars, with the Spatial platform selected to construct this virtual classroom. A key distinction from standard 3D tools is synchronous interactivity: the environment transcends passive observation, enabling students to collaboratively manipulate geometric shapes and solve problems as a group. It functions as a dynamic collaborative workspace rather than a static display.

The theoretical framework of this study integrates Model-Eliciting Activities (MEAs) [5] with the affordances of the Metaverse. While MEAs provide the cognitive structure for model construction, the Metaverse serves as the 'Concrete Experience' scaffold. By situating the MEA problem within an immersive 3D simulation, the Metaverse reduces the abstraction barrier, allowing students to visualize and manipulate spatial relationships directly. This alignment supports the "Reality Principle" of MEAs [5], enabling students to formulate more accurate initial models and test them dynamically. Consequently, this synergy enhances the connection between abstract geometry and physical reality, proving particularly valuable for spatial learning where 3D environments enable students to refine and test models with greater precision [25, 26].

This framework fosters mathematical connection skills through modeling activities (MEAs) embedded with Metaverse technology. Regarding the Reality Principle, students utilize virtual reality to bridge the gap between familiar, authentic situations and abstract mathematical concepts. The Model Construction Principle shifts the objective from merely finding an answer to constructing a system. Students must integrate multiple mathematical ideas to create 3D models that are functionally viable. Furthermore, through Model Documentation, they are required to articulate their cognitive processes via these models, externalizing their internal thinking into observable mathematical forms. This approach compels students to establish mathematical connections, as the successful completion of the task inherently necessitates these skills.

III. LITERATURE REVIEW

A. Learning Activities Using Model Eliciting-Activities (MEAs)

The distinguishing characteristic of Model-Eliciting Activities (MEAs) lies in their emphasis on model construction rather than mere answer-seeking. Unlike typical problem-solving, where students follow established procedures, MEAs require learners to articulate their cognitive processes, test them against real-world constraints, and revise them based on empirical feedback [5]. This iterative process compels students to make their reasoning visible, transforming vague ideas into concrete models amenable to peer discussion and refinement [27]. By engaging in these authentic scenarios, learners develop "mathematical power," transforming abstract theories into practical tools for analyzing complex systems [6].

One of the distinctive features of MEAs is their emphasis on collaborative learning. In these activities, students work together in groups to solve problems, share their strategies, and discuss their approaches, which brings an environment of active peer learning [2, 10]. This collaborative process helps develop teamwork skills, where students not only contribute their own ideas but also evaluate and integrate the ideas of others [28]. It also encourages students to reflect on and improve their problem-solving approaches, leading to a deeper understanding of the mathematical concepts they're working with [5, 11].

MEAs also help bridge the gap between abstract math concepts and real-world use. When students work on problems rooted in everyday situations, they begin to see how math applies to their own lives, which boosts their motivation and interest in the subject. [6, 29]. In this way, MEAs go beyond traditional problem-solving exercises, promoting an integrated approach to learning that combines mathematical thinking with real-world relevance. This approach not only strengthens students' mathematical abilities but also equips them with the critical thinking, collaboration, and decision-making skills needed for success in the modern world [3]. However, traditional MEAs often rely on static text or images, which may limit students' ability to fully visualize complex scenarios, creating a need for more immersive technologies [19, 23].

B. Virtual Social Technology

Virtual social technology, commonly known as the Metaverse, represents a transformative shift in education by creating immersive, interactive virtual environments where learners engage in experiences that simulate the real world through 3D visualizations, simulations, and augmented reality [11, 23]. This technology allows students to interact with content in a highly realistic and experiential manner, enabling them to explore complex concepts, scenarios, and environments that may be too difficult, dangerous, or expensive to recreate in traditional classrooms [30]. The Metaverse offers a dynamic learning platform that boosts active participation, critical thinking, and creativity, as students can engage in experiential activities, role-play, and simulations [22, 31].

The Metaverse breaks down geographical and time barriers, giving students access to worldwide resources and the chance to collaborate across cultures while solving problems in real time [28, 32]. It offers an unparalleled level of immersion and interactivity, where learners can experience and manipulate concepts in 3D spaces, enhancing understanding and retention [22, 23]. This ability to view and interact with 3D objects is especially important for math education, providing a concrete way to connect abstract geometric concepts with spatial understanding [13, 19].

C. Mathematical Connection Skills

Mathematical connection skills encompass the ability to meaningfully link mathematical knowledge, principles, and concepts to various problems and contexts. This involves utilizing logical reasoning, systematic thinking, and critical analysis to apply mathematical theories in real-world situations [1, 8]. These skills enable students to discern connections between different mathematical concepts and other disciplines such as science, economics, and engineering [2]. When students develop these abilities, they gain a broader perspective on how mathematics functions across diverse fields and real-world applications [4]. In the context of this study, mathematical connections are categorized into three forms: modeling connections (translating real-world scenarios into mathematical models), intra-mathematical connections (linking geometric concepts to algebraic or numerical ideas), and interdisciplinary connections (applying math to other contexts). These abilities are assessed through essay questions that require students to explicate their reasoning.

When students develop these connection skills, they can link abstract mathematical concepts to practical applications and understand why what they're learning matters. This deeper understanding helps them tackle complex real-world problems with the math they've learned [6, 11]. By recognizing how mathematical concepts are interconnected, learners can develop more robust problem-solving abilities and a more intuitive understanding of how mathematical models are applied to the real world [5, 12].

Furthermore, mathematical connection skills provide the foundation for interdisciplinary learning, where students can apply mathematics not just within its own field but also across various areas of study. This broader perspective helps students approach problems from diverse angles, using mathematical tools and methods to solve challenges in different fields such as engineering, technology, and social sciences [19]. These skills not only deepen students' mathematical understanding but also enhance their ability to make informed decisions and think critically in a variety of contexts [3, 10].

D. Academic Achievement in Mathematics

Academic achievement in mathematics is an essential aspect of evaluating students' mastery of mathematical knowledge and their ability to apply it in real-life contexts. It goes beyond merely assessing students' performance in standardized tests and includes their capacity for analytical thinking, problem-solving, and using mathematics as a tool for decision-making [1, 7]. This holistic approach recognizes that the ability to apply mathematical principles in novel situations is a key indicator of academic success in the subject [2].

To further develop academic achievement in mathematics, it is critical to focus on raising a deep understanding of mathematical concepts. Students should be encouraged to explore the relationships between different mathematical ideas, enabling them to connect abstract knowledge with practical applications [6]. This conceptual understanding is essential not only for solving problems but also for integrating mathematics into their daily lives, providing the foundation for lifelong learning and application in various fields [4, 12].

Moreover, enhancing academic achievement in mathematics involves creating an environment that encourages critical thinking, collaborative learning, and the development of higher-order thinking skills. By cultivating these abilities, students are better equipped to tackle complex mathematical challenges and adapt their knowledge to dynamic real-world problems. This way, math becomes more than just memorizing formulas—it equips students to apply what they know and adapt to new challenges in our evolving world [3, 10, 11].

Based on the literature review, it can be concluded that the synergistic integration of Model Eliciting Activities (MEAs), Virtual Social Technology (Metaverse), and Mathematical connection skills play an important role in enhancing participatory learning. While MEAs facilitate the cognitive synthesis of mathematical concepts through model building [5, 20], the Metaverse offers a transformative, immersive environment that transcends physical constraints, allowing students to contextualize these concepts in 3D spaces [21, 23]. As a result, this framework builds deeper mathematical understanding and helps students use abstract ideas to solve real-world problems, preparing them for long-term success in school and beyond [14, 16].

IV. MATERIALS AND METHODS

In this initial phase, the researcher conducted an analysis of the foundational data to develop the learning activity set that employs the Model Eliciting Activities (MEA) learning management approach [5] combined with virtual social technology (Spatial) [23, 28]. This process involved examining the core curriculum and relevant theories [1, 8], as well as surveying the needs of teachers and experts regarding the scope, content, and format of the learning activity set. Interviews with relevant stakeholders, along with analysis of documents, textbooks, and research on learning activity development [16, 33], were used to create an appropriate learning package for 6th-grade students through data triangulation.

A. Justification of the Sample Size

Nine sixth-grade students were selected through purposive sampling for a one-group pretest-posttest design. In this rural school, these students represented the entire Grade 6 population. While small, the sample size was appropriate for a pilot validation study designed to assess feasibility, examine the usability of the learning activity package, and evaluate its initial instructional effectiveness. Studies like this deliberately work with small, focused groups so researchers can observe closely and refine the approach before implementing it more broadly.

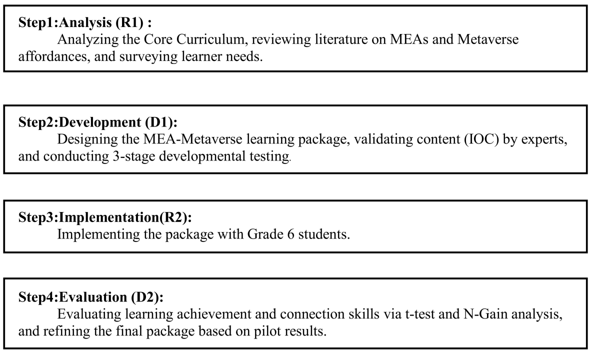
B. Validity and Reliability of the Research Instruments

To ensure content validity, instruments, including the mathematical connection skills test and achievement test, were developed based on the national curriculum standards [1] and reviewed by five experts in mathematics education and instructional design. The experts evaluated the consistency between test items and learning objectives using the Item-Objective Congruence (IOC) index, with resulting values ranging from 0.80 to 1.00, indicating high content appropriateness. Regarding reliability, the Learning Achievement Test (multiple-choice) demonstrated strong internal consistency with a Kuder-Richardson 20 (KR-20) coefficient of 0.853. For the Mathematical Connection Skills Test (essay-based), a standardized scoring rubric was validated by experts to ensure objectivity, and internal consistency was confirmed with a Cronbach's alpha coefficient of 0.87.

C. Bias Control and Trustworthiness

To minimize Novelty Effects associated with the Metaverse technology, the learning package underwent rigorous pilot testing to ensure usability [23]. Before data collection began, students participated in an orientation session to get familiar with the Spatial platform's interface and controls. To minimize teacher effects, the researcher served as a facilitator and followed the lesson plans closely to ensure consistency [11, 34]. Evaluation bias was minimized by standardizing scoring rubrics for all assessors. Finally, students' pretest and posttest results were evaluated using the same criteria and identical test conditions to reduce instrumentation bias.

Recognizing the limitations of a one-group pretest-posttest design and the introduction of new technology, several measures were taken to strengthen trustworthiness and reduce potential bias. To address the Novelty Effect—, where students may perform better simply because the technology is new, a preparatory field tryout ($N = 15$) was conducted with a different group before the main implementation to normalize students' exposure. In addition, the teacher's role was strictly defined as facilitator, following principles outlined by Walshaw and Anthony [27]. This approach focused on guiding students through the MEA process rather than direct instruction, which helped reduce the Teacher Effect. Finally, instrumentation bias was controlled by implementing validated instruments (Cronbach's $\alpha = 0.87$) and applying standardized scoring rubrics consistently across both pre- and posttests. Visual Flow of the R&D Procedure in Fig. 1.



Step1:Analysis (R1) :
Analyzing the Core Curriculum, reviewing literature on MEAs and Metaverse affordances, and surveying learner needs.

Step2:Development (D1):
Designing the MEA-Metaverse learning package, validating content (IOC) by experts, and conducting 3-stage developmental testing.

Step3:Implementation(R2):
Implementing the package with Grade 6 students.

Step4:Evaluation (D2):
Evaluating learning achievement and connection skills via t-test and N-Gain analysis, and refining the final package based on pilot results.

Fig. 1. R&D procedure flow for learning activity package development.

In this phase, the researcher developed the learning activity set based on data gathered in the analysis phase. The activity set integrates the MEA learning management approach [5] with virtual social technology to enhance students' mathematical linking skills [21, 23]. The researcher designed the learning activities to ensure alignment with the core curriculum [1]. This prototype was then reviewed by three experts for content validity and appropriateness, resulting in an Item-Objective Congruence (IOC) score of 1.00.

The effectiveness of the activity set was tested using the 80/80 efficiency criterion (E1/E2) based on the framework by Brahmawong [16]. In the context of instructional design development in Thailand, E1 (Process Efficiency) refers to the percentage of scores from formative assessments during the lessons, while E2 (Product Efficiency) refers to the percentage of scores from the summative post-test [16]. A standard threshold of 80/80 is widely accepted as an indicator of a high-quality instructional package [16].

To ensure the quality and suitability of the instructional package before full implementation, the researcher conducted a three-stage developmental testing process (1:1, 1:3, 1:15) following the developmental testing guidelines proposed by [16]. This systematic approach aims to identify and correct defects in content, language, and instructional sequencing step-by-step as follows:

1) Individual Tryout ($N = 1$): Conducted with one student to check initial usability. The efficiency met the 80/80 criterion, but feedback highlighted a need for more realistic 3D models, which were subsequently refined [16]
2) Small Group Tryout ($N = 3$): Conducted with students of mixed abilities (high, average, low). The efficiency score reached 80.53/80. Revisions focused on simplifying abstract problem scenarios to enhance clarity [16].
3) Field Tryout ($N = 15$): Conducted with a larger group to simulate a real classroom setting. The efficiency score reached 80.96/80.67, confirming that the package was effective. Adjustments were made to group management strategies to favor subgroups of 3–5 students for better discussion before the final implementation [16].

In this stage, the researcher implemented the developed learning activity set with the target group of 9 Grade 6 students at the target primary school, selected via purposive sampling. A pre-experimental research design (One Group Pretest–Posttest Design) was used to assess the students' mathematical linking skills and academic achievement. The intervention was conducted over 10 hours, during which the researcher acted as a facilitator to minimize teacher bias [11, 34]. The instruction followed the "MEA-Metaverse" learning cycle comprising four steps: (1) Exploring scenarios via Virtual Technology (Spatial), (2) Engaging with mathematical problems in the virtual context (Model Eliciting), (3) Presenting solutions via Virtual Technology, and (4) Evaluating and developing models.

During this final phase (D2), the researcher evaluated the instructional effectiveness by analyzing both quantitative and qualitative data. Quantitatively, students' academic achievement and mathematical linking skills were analyzed. Due to the limited sample size ($N = 9$), a Shapiro-Wilk test was first conducted to verify the normality of the data distribution. The results indicated that the data were normally distributed ($p > 0.05$), there by justifying the use of Dependent Samples t-tests to assess statistical significance. While the Shapiro-Wilk test confirmed data normality, the reported effect sizes (Cohen's d) should be interpreted as preliminary indicators of potential impact rather than definitive benchmarks, given the inherent volatility of effect sizes in small-scale pilot studies

Additionally, Normalized Gain (N-Gain) was calculated to measure individual learning progression using Hake's formula: N-Gain = (Post-score-Pre-score) / (Full Score-Pre-score) [5]. Qualitatively, student feedback and behavioral observations were analyzed to assess engagement and usability within the Metaverse environment [16, 29]. Based on these triangulated findings, the learning activity set underwent a final stage of refinement to optimize its appropriateness and scalability for future educational contexts [33].

V. RESULTS

Based on the needs assessment survey administered to 20 mathematics teachers within the local educational network, results indicated that the majority of participants possessed 1–10 years of teaching experience. There was a strong consensus that learning activities require clear instructional components that promote practical, hands-on learning. Teachers specifically emphasized the necessity of group-based learning and the integration of virtual social technology to facilitate the visualization of 3D geometric shapes. Furthermore, assessment methods should be diversified, incorporating both written responses and behavioral observations of activity performance. Qualitative data from interviews with 7 experts (5 in learning activity development and 2 subject matter specialists) reinforced these findings. Experts emphasized that using virtual worlds to simulate real-life situations is essential for developing critical thinking, problem-solving, and the ability to connect math to everyday life. They suggested organizing small-group collaboration in virtual reality environments to support design work and simulations, boosting both communication skills and engagement. Assessment approaches should comprehensively measure how students develop mathematical connections.

The development of the learning activities using Model-Eliciting Activities (MEAs) combined with virtual social technology aimed to enhance mathematical connection skills and academic achievement in mathematics for 6th-grade students. The learning activities consisted of five main components: 1) Teacher's manual, 2) Guidelines, 3) MEA-Metaverse activities structured in a four-step cycle (Studying real-life events, facing mathematics problems, presenting solutions, and Assessing solutions via virtual technology), 4) Learning media, and 5) Assessments.

The effectiveness of the learning activities was first evaluated by five experts, yielding an average appropriateness score of 4.90 (out of 5.00), indicating a high level of quality. The activities were then empirically tested for efficiency (E1/E2) through three tryout stages. The Individual Tryout (N = 1) met the 80/80 criterion. The Small Group Tryout (N = 3) achieved an efficiency score of 80.53/80. Furthermore, a Field Tryout (N = 15) conducted with students from another local primary school (non-sample group) yielded an efficiency score of 80.96/80.67. After refining the activities based on feedback, the final learning activity on 3D geometry was implemented with the target group of nine 6th-grade students at the target primary school. The final efficiency score reached 83.48/83.33, which exceeds the set threshold of 80/80.

A pilot study with nine 6th-grade students at the target school, conducted over 10 h, showed significant improvements in both mathematical connection skills and academic achievement.

Qualitative observations indicated that students were highly engaged, exhibiting positive emotional responses and sustained interest throughout the lessons.

The intervention showed substantial results beyond just statistical significance ($p < 0.05$). Effect size analysis revealed very large impacts (Cohen's $d = 1.92$ for mathematical connection skills and $d = 1.75$ for academic achievement), indicating that the integrated package improved performance well beyond what traditional instruction typically achieves

Theoretically, these substantial gains can be attributed to the synergy between MEA pedagogy and Metaverse affordances. Following [15], MEAs required students to externalize and refine mathematical models, while the immersive environment supported this process. The 3D visualization tools weren't just technological novelties—they helped students think spatially, while the MEA structure kept learning authentic and collaborative. The structure of the learning activity set is presented in Fig. 2 [35, 36].

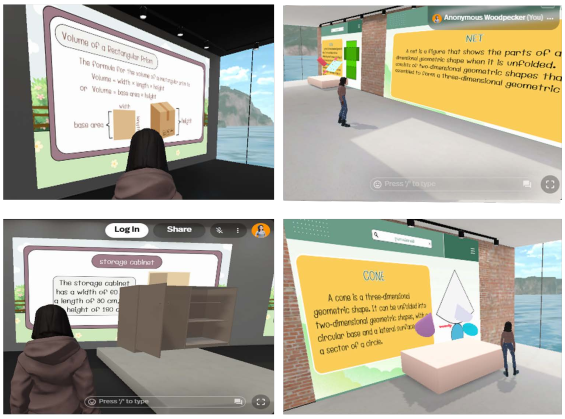


Fig. 2. Learning activity set.

Table 1 presents the comparison of mathematical connection skills before and after the learning management. The analysis revealed a statistically significant improvement ($p < 0.05$). This combined cognitive effect resulted in deeper conceptual transfer and sustained learning progression. Post-test scores were markedly higher than pre-test scores, confirming the effectiveness of the 3D geometry learning activity set.

Table 2 presents a comparison of academic achievement before and after the intervention. The results revealed a statistically significant improvement ($p < 0.01$). Furthermore, the analysis of learning progression yielded a Normalized Gain (N-Gain) of 0.70. According to the standard benchmarks, this indicates a high level of improvement, confirming the effectiveness of the MEA approach combined with virtual social technology in enhancing students' mastery of 3D geometric concepts.

Table 3 presents the Normalized Gain (N-Gain) analysis for the mathematics subject. The results indicate an N-Gain of 0.70. This value signifies that students achieved 70% of their maximum possible learning potential. According to standard benchmarks, this is classified as a High Gain level, confirming that the intervention resulted in a substantial advancement in students' conceptual understanding. Effect size analysis showed impressive results (*d* = 1.92 and *d* = 1.75). With only nine students, results can swing considerably, so this shouldn't be generalized too far. These findings demonstrate feasibility and suggest the approach has potential.

Table 1. Comparison of mathematical connection skills before and after learning management using the learning activity set

Learning Outcomes	Number of Students (n)	Full Score	Mean ($\bar{X}$)	S.D.	*t*-test	Sig.	Cohen's *d*
Pre-test Scores	9	25	8.22	2.66	3.35*	0.000	1.92
Post-test Scores	9	25	16.56	2.22			

Note: * $p < 0.05$.

Table 2. Comparison of learning achievement of 6th-grade students before and after learning using the learning activity set

Learning Outcomes	Number of Students (n)	Full Score	Mean ($\bar{X}$)	S.D.	*t*-test	Sig.	Cohen's *d*
Pre-test Scores	9	20	8.78	1.31	3.44**	0.009	1.75
Post-test Scores	9	20	16.67	2.55			

Note: ** $p < 0.01$.

Table 3. Progress in learning (N Gain) for mathematics subject before and after using the learning activity set

Before Learning	After Learning	Actual Gain	Maximum Possible Gain	Normalized Gain	Interpretation
8.78	16.67	39.44	56.11	0.70	High Gain

VI. DISCUSSION

The findings from the study reveal that the Model Eliciting Activities MEAs approach, integrated with virtual social technology, emphasizes meaningful student engagement in solving real-life problems [5, 6]. The integration of virtual social technology enhances the realism of the activities, allowing students to interact with 3D geometric shapes in a virtual environment. This promotes the development of spatial skills and knowledge integration (Reality Principle), aligning with MEA principles [5, 23].

The study also showed that learning activities should focus on students, with teachers acting as facilitators [11]. Teachers and experts emphasized the importance of group-based activities and the use of virtual technology to enhance collaboration and communication. This integration supports the development of 21st-century skills, including critical thinking and problem-solving [3]. Findings from the needs assessment and expert interviews further reinforced the need for clear structure, practical content, and diverse evaluation methods. This consensus confirms that combining MEAs with virtual simulations effectively supports mathematical reasoning and spatial awareness across different contexts [5, 23].

The findings reveal that the developed learning activity set possesses a high level of quality, characterized by comprehensive components including teacher manuals, guidelines, assessments, and activity sheets. These elements align with the approach of Reiser and Dempsey [33] regarding essential teaching media. Designed to promote student engagement, the activities utilize the MEA framework to foster systematic thinking [5], while the integration of virtual social technology enhances spatial skills by providing 3D environments for knowledge application [21, 23].

The learning activities proved effective across individual, small group, and field trials, scoring 83.48/83.33, which is above the 80/80 standard. This confirms that the tool effectively helped students reach their learning goals, consistent with [16]. Consequently, the package is deemed suitable in terms of content, process, and format, successfully enhancing students' mathematical connection skills and critical thinking in primary school contexts.

The implementation results revealed that students were highly engaged and motivated, demonstrating enthusiasm for studying content through virtual technology [29]. They actively connected real-world scenarios to daily life, consistent with [34], who emphasized that relating authentic situations to mathematical knowledge leads to effective problem-solving and deeper understanding. This high level of engagement was particularly driven by the Metaverse's ability to provide an interactive, non-threatening environment for experimentation and co-creation [37].

Additionally, the integration of virtual social technology enhanced the spatial learning experience by presenting 3D representations that facilitated visualization and conceptual comprehension [13, 19]. This visualization acts as a cognitive scaffold, making abstract mathematical connections more concrete and accessible. The activities moved systematically from engagement to challenging collaborative problems, encouraging critical thinking and peer discussion. This pedagogical design, combined with immersive technology, resulted in statistically significant improvements in both test scores and the ability to link mathematical knowledge [14].

The nine students represent the school's entire sixth-grade class in a small school in Southern Thailand. This scale actually highlights an advantage: bringing cutting-edge instruction to students who might otherwise lack access. Observations showed students genuinely engaged, explaining aloud how the virtual 3D nets related to real-world geometry. This wasn't rote learning; they grasped the underlying concepts.

The evaluation results demonstrated statistically significant improvements in both mathematical connection skills and academic achievement post-intervention ($p < 0.05$). This significant growth confirms the learning activity effectively built key competencies, aligning with [10, 12], which emphasize connecting math concepts to real-world situations for better problem-solving. Furthermore, the average Normalized Gain (N-Gain) of 0.70 signifies a "High Gain" in learning progression [13].

A normalized gain of 0.70 indicates that MEAs and the Metaverse work well together for developing mathematical connections. Through the Reality Principle, the Metaverse transformed typical word problems into interactive scenarios where students could explore and experiment. This bridged their everyday experience with formal mathematics. The Model Construction component let students physically manipulate 3D shapes in Spatial, providing concrete support as they integrated various mathematical elements into functional models.

This substantial development reflects the successful synergy of MEA-based problem-solving and VR technology. Research shows that immersive virtual environments improve student satisfaction and outcomes by developing spatial skills, analytical thinking, and collaboration, which are the key elements of 21st-century education [3, 5, 22].

The significant improvement in both mathematical connection skills and academic achievement demonstrates the strong potential and initial effectiveness of the MEA-Metaverse learning package.

Caution must be exercised when generalizing these results. With only nine students and no control group, we can't say definitively what caused the improvements. The Metaverse itself might have boosted performance simply because it was new and exciting—what researchers call the novelty effect. Students may have also gotten better at the tests through repeated exposure. To really understand whether the MEA-Metaverse combination drives these gains, we'd need a larger study with a control group that can distinguish between these different factors.

VII. CONCLUSION

This pilot study demonstrates that combining Model-Eliciting Activities (MEAs) with virtual social technology effectively supports mathematical connection skills in primary students. The developed instructional package met high efficiency standards and corresponded with notable improvements in both academic achievement and conceptual understanding. The immersive Metaverse environment appeared particularly effective, allowing students to visualize and manipulate 3D models. This concrete experience supported the spatial thinking required by MEAs while keeping students actively engaged. However, given the limited sample size ($N = 9$) and the lack of a control group, these results should be interpreted as preliminary evidence rather than definitive proof. The study contributes a validated framework and a working prototype for educators, serving as a foundation for future research. Subsequent studies with larger sample sizes and control groups are recommended to verify these findings and isolate the specific impact of the instructional model from the technological novelty effect.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Sasiton Muangmor was responsible for the research conceptualization, development of the learning activity package, data collection, and formal analysis. Rossarin Jermtaisong provided principal supervision, applying her expertise in curriculum development and teacher education to guide the research methodology and instructional design. Pornpilhom Lhongsap served as the Curriculum Chair, providing expert consultation on curriculum design and implementation, and offered continuous guidance throughout the research process. All authors have read and agreed to the published version of the manuscript.

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