INTERNATIONAL JOURNAL OF  
EDUCATION, PSYCHOLOGY  
AND COUNSELLING  
(IJEPC)<https://gaexcellence.com/ijepe>ENHANCING MATHEMATICAL LITERACY THROUGH  
METAVERSE-BASED LEARNING:  
A CONCEPTUAL FRAMEWORK FOR LOWER  
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**Article Info:****Article history:**

Received date: 26.07.2026

Revised date: 10.08.2026

Accepted date: 30.08.2026

Published date: 29.09.2026

**To cite this document:**

Hassan, D., Kamu, A., Ho, C. M., & Anggang, A. I. (2026). Enhancing Mathematical Literacy Through Metaverse-Based Learning: A Conceptual Framework for Lower Secondary Students in Malaysia. *International Journal of Education, Psychology and Counselling*, 11(64), 1720-1740.

**Abstract:**

Mathematical literacy requires students to use mathematics meaningfully when responding to problems both within and beyond the classroom. However, applying mathematical knowledge in unfamiliar and contextualised situations remains challenging for many learners. This conceptual paper examines how metaverse-based learning may support mathematical literacy among lower secondary students in Malaysia. Drawing on constructivist perspectives and literature on immersive learning and mathematics education, the paper develops a framework centred on Minecraft Education. The framework considers immersion, interaction, collaboration, and visualisation as affordances of the learning environment rather than assuming that the use of immersive technology itself leads to improved learning. Their educational relevance is considered through three learning processes: student engagement, spatial reasoning, and mathematical problem-solving. These processes are linked to mathematical literacy through students' ability to formulate situations mathematically, employ appropriate mathematical concepts and procedures, and interpret or evaluate mathematical outcomes in context (OECD, 2023). Geometry, measurement, coordinates, and ratios are identified as possible mathematical contexts for applying the framework rather than as constructs within it. As the paper is conceptual, no intervention or

experimental findings are reported. A quasi-experimental approach is instead presented as one possible direction for future empirical validation in Malaysian lower secondary classrooms. By distinguishing the affordances of the learning environment from the processes through which students engage with mathematics, the framework offers a basis for investigating how immersive learning experiences may contribute to mathematical literacy.

**DOI:** 10.35631/IJEPC.1164095

**Keyword:**

Mathematical Literacy; Metaverse-Based Learning; Minecraft Education; Mathematics Education; Lower Secondary Students.



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## Introduction

Mathematical literacy refers to the ability to make meaningful use of mathematics when dealing with situations that extend beyond routine classroom exercises. In the OECD (2023) framework, this involves formulating situations mathematically, employing mathematical knowledge, and interpreting the results. Knowing a procedure is therefore only one part of being mathematically literate. Students also have to recognise when mathematics is relevant, identify relationships within the information available, choose a suitable approach, and consider whether the answer makes sense in the situation being examined (Niss & Jablonka, 2020; Stacey, 2021). This broader view is particularly important because young people increasingly encounter information presented through numbers, data, diagrams, measurements, and spatial representations in both school and everyday life.

The difficulty is that competence with classroom mathematics does not always transfer easily to unfamiliar situations. A student may know how to carry out a calculation when the required method is obvious but struggle when the problem must first be interpreted. PISA results continue to show difficulties with tasks that place greater demands on mathematical reasoning and the use of mathematics in context (OECD, 2023). TIMSS findings similarly indicate that applying mathematical understanding in less familiar situations can be challenging for students (Mullis et al., 2024). For Malaysian mathematics education, this suggests a need for learning experiences in which students have to decide what information matters, determine how mathematics can be used, and make sense of the solution rather than simply reproduce a familiar procedure.

Digital environments offer possibilities for designing these kinds of experiences. Mathematical relationships that may appear abstract on a printed page can sometimes be explored through visual representations or through objects that learners can manipulate. Students can test an idea,

observe what changes, and reconsider their initial thinking as they work (Bond et al., 2021; Trouche et al., 2022). Yet the use of technology should not be treated as an educational benefit in itself. Bower (2023) emphasises the importance of how learning with technology is designed and experienced. From this standpoint, the relevant question is not simply whether a digital tool is present in a mathematics lesson, but what kind of mathematical activity that tool makes possible.

This question becomes particularly interesting in immersive environments. The metaverse provides three-dimensional virtual spaces where learners can engage with digital objects, content, and other participants through virtual representations (Mystakidis, 2022). Such environments can provide experiences that differ from conventional online learning, particularly in the ways learners interact, collaborate, explore, and work with visual representations (Kye et al., 2021). Minecraft Education illustrates this potential. Within its virtual space, students can construct objects, alter them, move between locations, and examine their work from different positions. They can also carry out tasks with other learners in the same environment. These actions have clear possibilities for mathematics. A geometry task, for example, can involve constructing and examining an object rather than viewing only a two-dimensional drawing, while measurement, coordinates, and ratios can be incorporated into problems situated within the virtual world.

Recent research has increasingly focused on immersive and metaverse-based education. Reported outcomes include changes in engagement, motivation, collaborative learning, and academic performance (Dwivedi et al., 2022; Geng & Su, 2024; Tlili et al., 2022). These findings establish a useful starting point, but they leave a more specific issue unresolved. Positive experiences with an immersive environment do not necessarily show that students are developing mathematical literacy. A learner might be highly engaged with a virtual activity and still have difficulty deciding how to represent a real-world problem mathematically. Similarly, improved performance on a learning task does not reveal whether the learner has become better at selecting appropriate mathematics or judging what a mathematical result means in its original context. For the present study, the important issue is therefore the connection between what an immersive environment allows students to experience and the mathematical thinking that takes place during that experience.

Three learning processes appear especially relevant to this connection. The first is student engagement. Participation matters because students need to remain involved long enough to examine a mathematical situation, try an approach, and respond when their initial solution does not work (Bond et al., 2021). The second is spatial reasoning. This is particularly relevant when learners deal with shape, position, measurement, visualisation, and relationships between objects in space (Hawes et al., 2022; Lowrie et al., 2023). An immersive environment may give students opportunities to examine these relationships from perspectives that are difficult to reproduce using static representations. The third process is mathematical problem-solving. When a problem is contextualised, students cannot always begin by applying a familiar formula. They must first understand the situation, decide what mathematics is relevant, and then interpret what their solution tells them. These actions overlap closely with the formulation, employment, and interpretation processes associated with mathematical literacy (OECD, 2023).

Considering these processes together changes the way the role of the metaverse can be understood. Immersion, interaction, collaboration, and visualisation should not be assumed to improve mathematical literacy directly. Their value depends on what students are prompted to think about and do while learning. Visualisation, for instance, may help a learner notice a spatial relationship that was difficult to understand in a static diagram. Interaction may allow an idea to be tested by changing an object and observing the result. Collaboration can require students to explain why they chose a particular solution and respond to alternative reasoning from their peers. Immersion may help sustain attention within a problem situation. The proposed relationship is therefore not simply between the technology and an eventual learning outcome; learning processes provide the conceptual link between them.

This relationship has received comparatively limited conceptual attention in the Malaysian lower secondary context. The existing literature provides important evidence concerning immersive technology and learning, but it does not yet offer a sufficiently developed explanation of how metaverse affordances could be connected with the development of mathematical literacy among Malaysian lower secondary students. This distinction matters. Introducing Minecraft Education or another immersive platform into a lesson does not, by itself, explain why mathematical literacy should improve. An explanation is needed of what particular features of the environment enable students to do mathematically and how those experiences relate to the abilities involved in using mathematics in context.

The framework proposed in this paper is developed around that relationship. It identifies immersion, interaction, collaboration, and visualisation as affordances of metaverse-based learning and considers how they may operate through student engagement, spatial reasoning, and mathematical problem-solving. Mathematical literacy forms the intended outcome and is understood through students' capacity to formulate, employ, and interpret mathematics in meaningful situations. The framework therefore separates the features provided by the learning environment from the processes through which students engage with mathematics. This distinction is important because it avoids treating the metaverse itself as the cause of learning. Constructivist perspectives, together with research in immersive learning and mathematics education, inform the proposed relationships. Geometry, measurement, coordinates, and ratios provide possible mathematical settings in which the framework could later be applied; they are not variables within the framework. The paper is conceptual, and no classroom intervention is reported. A quasi-experimental design is therefore included only as a possible direction for later empirical testing. The purpose at this stage is to develop an explanation of how metaverse affordances might support the engagement, spatial reasoning, and problem-solving involved when students learn to formulate, use, and interpret mathematics in context.

## Literature Review

### *Mathematical Literacy*

Mathematical literacy has become increasingly important because students are expected to use mathematics in situations that do not always resemble the exercises they encounter in the classroom. Knowing mathematical facts and procedures remains important, but this alone does not ensure that students can use mathematics effectively. They also need to recognise when mathematics is relevant to a situation, decide how to approach a problem, and make sense of the result. The OECD (2023) describes mathematical literacy in terms of mathematical reasoning and the capacity to formulate, employ, and interpret mathematics across a range of

real-world contexts. Niss and Jablonka (2020) likewise emphasise the ability to draw on mathematical knowledge when people need to understand, judge, or respond to situations involving mathematics.

For the purpose of this paper, mathematical literacy is considered through three connected processes derived from the PISA framework: formulating situations mathematically, employing mathematical concepts and procedures, and interpreting and evaluating mathematical outcomes (OECD, 2023). Organising the construct in this way makes it possible to examine not only whether students can perform mathematics, but also how they move between a contextual situation and its mathematical representation.

### ***Formulating Situations Mathematically***

Formulation begins before a calculation is carried out. When students encounter a contextual problem, they first need to work out what information is important and what mathematical relationships may be present. This can involve making assumptions, selecting relevant quantities, identifying patterns or relationships, and representing aspects of the situation mathematically. Unlike routine exercises, contextual problems may not indicate which formula, operation, or procedure to use. Students have to make that decision themselves. Their ability to recognise the mathematics within the situation is therefore an important part of mathematical literacy.

### ***Employing Mathematical Concepts and Procedures***

Once a situation has been represented mathematically, students need to work with that representation. Depending on the problem, they may carry out calculations, select a strategy, use different representations, identify a pattern, or reason towards a possible solution. The important point is that mathematical knowledge has to be used purposefully. Procedural fluency remains relevant, but students must also decide which knowledge or procedure is appropriate for the particular problem they are trying to solve (OECD, 2023; Stacey, 2021).

### ***Interpreting and Evaluating Mathematical Outcomes***

A mathematical answer does not complete the process. Students must return to the situation that produced the problem and consider what their result actually means. They may need to judge whether an answer is realistic, determine whether it satisfies the original conditions, explain its significance, or recognise limitations in the assumptions and representations they used. Interpretation and evaluation are therefore what reconnect mathematical work with the context from which it emerged.

Viewing mathematical literacy through these three processes helps distinguish it from procedural achievement alone. A student might calculate accurately when the required procedure is given but struggle to decide whether that procedure is appropriate in an unfamiliar situation. Another student may obtain a numerical answer yet be unable to explain what the answer means in relation to the problem. Mathematical literacy consequently involves movement in both directions: from a real situation into mathematics and from the mathematical result back into its original context.

Evidence from international assessments suggests that this movement remains challenging for many students. Performance on familiar mathematical procedures does not necessarily transfer to non-routine tasks or those embedded in contextual situations (OECD, 2023; Mullis et al., 2024). Research on mathematical literacy has also highlighted reasoning and the application of mathematical understanding across different contexts (Haara et al., 2022). This suggests that extensive practice with procedures, while useful, may not provide all of the experience's students require to become mathematically literate.

The design of the learning environment becomes important in this respect. Students need opportunities to encounter problems where the mathematical approach is not entirely predetermined. They should have room to examine a situation, decide how to represent it, try mathematical ideas, reconsider their approach, and determine whether the resulting solution is sensible. Technology-supported environments may contribute to such experiences when they allow mathematical processes or relationships to be explored in ways that static representations cannot easily provide (Trouche et al., 2022; Bower, 2023).

This interpretation of mathematical literacy also provides a basis for examining metaverse-based learning. Immersion, interaction, collaboration, and visualisation should not themselves be regarded as evidence of mathematical literacy. They are characteristics of a learning environment. Their relevance lies in whether they give students meaningful opportunities to recognise mathematics in a contextual problem, work with mathematical ideas, and make sense of the solutions they produce.

Geometry, measurement, coordinates, and ratios offer useful settings for considering these possibilities because they can be represented and manipulated within three-dimensional spaces. Consider a student who is asked to construct a virtual structure. Before building it, the student may need to identify the dimensions or relationships required by the task. Mathematical concepts can then be used during construction, after which the completed structure can be checked against the original conditions. In such an activity, the mathematical topic provides the content through which literacy is practised; it is not itself a construct within the proposed framework.

This distinction defines the role of mathematical literacy in the present paper. Mathematical literacy is the intended outcome and is represented by formulation, employment, and interpretation or evaluation. Metaverse affordances and the learning processes associated with them are examined as possible contributors to that outcome. Keeping these elements conceptually separate is necessary before their relationships can be examined empirically.

### ***Theoretical Foundation***

Constructivist learning theory provides the primary theoretical foundation for the proposed framework. From a constructivist perspective, learners develop understanding through their experiences and through active engagement with ideas, tasks, and other people. Learning is not viewed simply as information moving from the teacher to the student. Instead, learners relate new experiences to what they already understand and revise that understanding as they explore, discuss, and test ideas (Piaget, 1972; Vygotsky, 1978). This perspective is relevant to mathematics because conceptual understanding often develops while learners represent relationships, reason about possibilities, discuss alternative approaches, and work through problems.

This view helps explain why an environment such as Minecraft Education may have educational value for mathematical literacy. Students can encounter mathematical ideas within a three-dimensional setting rather than only through written descriptions. They can construct and alter objects, inspect spatial relationships, discuss possible solutions, and make changes when an initial approach does not produce the expected result. What matters from a constructivist standpoint is not the immersive technology by itself. Its value comes from the mathematical activity and knowledge construction that the environment can support.

Vygotsky's (1978) emphasis on the social character of learning adds another dimension. Students can develop understanding while explaining their reasoning, comparing approaches, questioning one another, and working towards a shared solution. A metaverse environment can provide a setting for this kind of activity when learners work together on mathematical problems. Collaboration is therefore relevant because of the mathematical exchanges it can make possible, not merely because several students can occupy the same digital space.

Technology-mediated learning offers a complementary perspective. Bower (2023) draws attention to the ways technological affordances influence interactions involving learners, content, activities, and other participants. This is an important distinction for the present framework. The presence of sophisticated technology does not automatically improve learning. Its educational significance depends on what learners are able to do with it and on how those possibilities are incorporated into the learning task.

Four affordances are of particular interest in the proposed framework: immersion, interaction, collaboration, and visualisation. Immersion situates students within the virtual setting in which an activity takes place. Interaction gives them opportunities to manipulate objects or respond directly to mathematical representations. Collaboration allows ideas and possible strategies to be developed with other learners. Visualisation enables spatial and mathematical relationships to be examined in three-dimensional form. These affordances describe possibilities provided by the environment. Whether those possibilities result in mathematical learning depends on how students engage with them.

For this reason, the framework places student engagement, spatial reasoning, and mathematical problem-solving between the technological affordances and mathematical literacy. They represent learning processes through which features of the environment may acquire educational significance. An immersive task, for example, may encourage a learner to remain involved in a problem for longer. Manipulating a three-dimensional representation may help the learner examine a spatial relationship from a different perspective. A contextual challenge may require the student to decide which mathematical information is relevant rather than simply apply a procedure supplied in advance.

These processes can also be related to the three dimensions of mathematical literacy identified by the OECD (2023). Within a contextualised virtual task, students may first have to recognise the mathematical structure of the situation and represent it in a usable form. They can then apply relevant concepts, representations, or procedures while developing a solution. Finally, they need to consider what that solution means in relation to the conditions of the task. The proposed relationship is therefore indirect: the environment provides certain possibilities, those possibilities may support particular forms of learning activity, and those learning processes may contribute to students' ability to formulate, employ, and interpret mathematics.

The two theoretical perspectives serve related but different purposes in this explanation. Constructivism accounts for the active and social development of mathematical understanding, whereas technology-mediated learning helps explain how features of a digital environment can shape the experiences available to learners. Bringing these perspectives together supports the proposed sequence from metaverse affordances to learning processes and, subsequently, to mathematical literacy.

### ***Proposed Conceptual Framework***

The literature discussed above suggests that metaverse-based environments may provide useful conditions for mathematics learning, particularly when students can interact with representations, examine spatial relationships, collaborate with peers, and work within contextualised virtual situations. The significance of these possibilities for mathematical literacy, however, depends on the learning activity that occurs between the use of the technology and the intended outcome.

The proposed framework is consequently organised into three components. The first concerns what the metaverse learning environment affords students. The second concerns the learning processes that may arise as students work within that environment. The third concerns the mathematical-literacy outcome towards which those processes are directed. Minecraft Education provides the instructional setting in which these relationships can be explored.

The first component comprises immersion, interaction, collaboration, and visualisation. Immersion concerns the experience of working from within a three-dimensional virtual setting. Interaction refers to what students can do with objects and mathematical representations in that space. Collaboration concerns opportunities to develop ideas and solutions with peers. Visualisation relates to the representation and exploration of mathematical or spatial relationships in forms that students can observe and manipulate. These four affordances describe characteristics of the learning experience rather than measures of learning achievement.

The second component consists of student engagement, spatial reasoning, and mathematical problem-solving. Their role is important because they help explain how environmental affordances might be translated into mathematical activity. Engagement concerns the extent to which students participate and persist while working on a task. Spatial reasoning involves making sense of positions, shapes, dimensions, transformations, and other relationships in space. Mathematical problem-solving concerns understanding a problem, identifying its mathematical features, selecting an appropriate approach, and developing a solution that can be justified. Existing literature supports the relevance of engagement to learning (Bond et al., 2021) and the connection between spatial reasoning and mathematics performance (Hawes et al., 2022; Lowrie et al., 2023).

Mathematical literacy forms the third component and the principal outcome of the framework. Consistent with the PISA perspective, it is represented through the capacity to formulate situations mathematically, employ mathematical concepts and procedures, and interpret or evaluate mathematical outcomes in context (OECD, 2023). The emphasis is consequently on using mathematics meaningfully rather than demonstrating procedural knowledge in isolation. The framework does not assume that mathematical literacy improves merely because students use Minecraft Education or another immersive platform. Instead, it proposes a sequence of

relationships. Features such as visualisation or interaction may provide students with particular ways of approaching a task. Those experiences may support engagement, spatial reasoning, or problem-solving, which can then provide opportunities to practise the processes involved in mathematical literacy. This interpretation is consistent with constructivist learning because students are expected to develop understanding through activity and interaction. It is also consistent with a technology-mediated perspective because the educational effect depends on what the technological environment enables within the learning task (Bower, 2023).

Geometry, measurement, coordinates, and ratios can be used to illustrate how the proposed relationships might operate. Students could construct a virtual structure and determine appropriate dimensions, use coordinates to locate objects, compare measurements through ratios, or investigate geometric relationships by manipulating a construction. These topics provide mathematical content through which the framework can be implemented. They are not independent variables or additional constructs within the conceptual model, and other mathematical content could also be used where it supports meaningful application.

The conceptual pathway can therefore be represented as:

Metaverse learning affordances → Learning processes → Mathematical literacy

More specifically, immersion, interaction, collaboration, and visualisation represent the affordances of the learning environment; student engagement, spatial reasoning, and mathematical problem-solving represent the processes through which students engage mathematically with that environment; and formulating, employing, and interpreting or evaluating mathematics represent the mathematical-literacy outcome.

This structure avoids attributing learning directly to the technology. Instead, it proposes that the educational value of metaverse-based learning depends on the kinds of mathematical experiences its affordances make possible and on the learning processes through which students respond to those experiences. The framework thus provides a conceptual explanation of how an immersive environment may contribute to mathematical literacy while keeping the technological affordances, learning mechanisms, mathematical content, and intended outcome analytically distinct. The relationships among the metaverse learning affordances, learning processes, and mathematical literacy outcomes described above are summarised in the proposed conceptual framework presented in Figure 1.

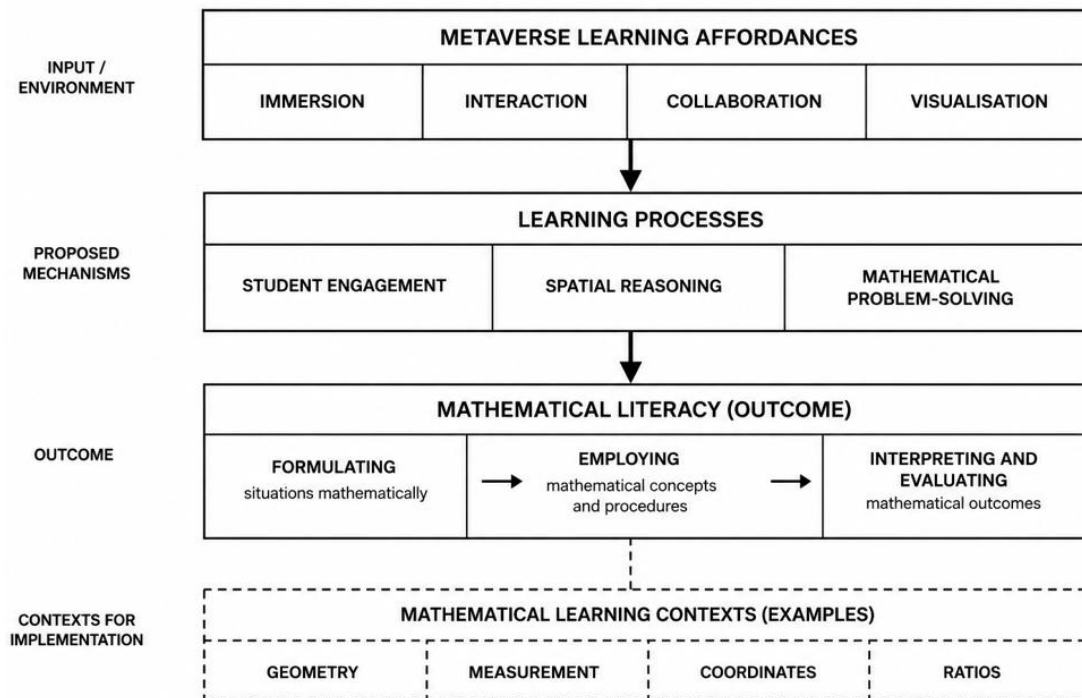


**Figure 1: Proposed Conceptual Framework for Metaverse-Based Learning and Mathematical Literacy**

### *Proposed Empirical Validation*

The present paper is conceptual and does not report experimental data. Empirical testing would therefore be a subsequent stage of the research rather than part of the current study. One possible approach is a quantitative quasi-experimental study using a non-equivalent pretest–posttest control group design (Creswell & Creswell, 2023; Cohen et al., 2021). Such a design is appropriate for school-based research where existing classes often need to remain intact and randomly assigning individual students may not be feasible.

### *Participants and Group Assignment*

Future validation could involve lower secondary students enrolled in Malaysian secondary schools. Rather than reorganising students into newly formed groups, existing classes could be retained so that the study causes minimal disruption to normal teaching arrangements. Two classes with reasonably similar academic backgrounds could be selected. One class would experience the metaverse-based approach, while the other would continue with conventional mathematics instruction.

Before instruction begins, students in both classes would complete a mathematical literacy pre-test. The same construct would then be assessed following the intervention. The pre-test is important because intact classes cannot be assumed to be equivalent at the outset. Baseline results would make it possible to examine initial differences before considering changes in mathematical literacy following the two instructional conditions.

Students in the treatment class would learn through activities developed for Minecraft Education. Those in the comparison class would study corresponding mathematical content without the metaverse-based environment. This arrangement would provide a basis for examining whether patterns of change differ between students experiencing the two forms of instruction.

### ***Instructional Control***

The comparison between groups would need to be structured carefully. Both classes should address the same curriculum content and learning objectives and receive approximately the same amount of instructional time. The principal difference should concern the way students experience and work with the mathematical activities.

Teachers responsible for the metaverse condition would need prior guidance on the planned Minecraft Education activities and on their role in facilitating students' mathematical thinking. Teaching in the comparison condition would follow established classroom approaches, including teacher explanation, guided exercises, mathematical discussion, and written tasks.

Keeping curriculum coverage, intended learning outcomes, and instructional duration reasonably consistent would reduce the likelihood that differences in performance were simply the result of one group receiving more time or different mathematical content. The comparison would consequently focus more clearly on the instructional experiences associated with the two conditions.

### ***Proposed Intervention***

A period of approximately six to eight weeks could provide an initial setting for testing the framework. During this period, students in the treatment class would complete contextualised mathematics activities in Minecraft Education. Geometry, measurement, coordinates, and ratios could provide the mathematical content for these activities. As established in the conceptual framework, these topics would serve as contexts in which mathematical literacy can be practised rather than as variables to be tested independently.

The activities would incorporate the four metaverse affordances identified in the framework: immersion, interaction, collaboration, and visualisation. Their inclusion should be reflected in what students actually do during the lessons. For example, students might construct a virtual structure and determine appropriate dimensions, locate or position objects using coordinates, investigate geometric relationships by manipulating constructions, or use ratios to compare quantities within a task. Some challenges could require students to develop a solution jointly, explain their choices to peers, and modify their work when the proposed solution fails to meet the conditions of the problem.

The teacher's role would extend beyond helping students operate Minecraft Education. During the activities, the teacher could question students about why they selected a particular mathematical approach, ask them to justify decisions, and encourage them to relate what they observe in the virtual environment to the mathematical concepts being studied. These interactions are important because the framework does not assume that exposure to an immersive environment automatically produces mathematical learning.

Students in the comparison class would study comparable mathematical content during the same general period through conventional instructional activities. The intention would not be to remove discussion or problem-solving from the comparison condition, but to examine learning without the specific immersive, interactive, collaborative, and visual features incorporated into the metaverse-based activities.

### **Measurement of Mathematical Literacy**

Mathematical literacy would constitute the principal outcome for empirical validation. Following the PISA perspective adopted throughout the framework, assessment would focus on students' ability to formulate situations mathematically, employ mathematical concepts and procedures, and interpret or evaluate mathematical outcomes within context (OECD, 2023).

For this reason, an assessment composed only of routine computational questions would not adequately represent the intended outcome. Students would need to encounter contextualised items in which the mathematical approach is not always stated explicitly. A task might ask them to identify relevant information, determine how the situation can be represented mathematically, select and use an appropriate strategy, and then judge or explain the result in relation to the original context.

Mathematical literacy would be assessed before and after the instructional period. Using the same underlying construct at both points would make it possible to examine how performance changes over time and whether the pattern of change differs between the metaverse-based and conventional instructional conditions.

Where possible, the assessment should also permit examination of the three mathematical literacy processes separately. This would be useful because an overall change in mathematical literacy may conceal different patterns across formulation, employment, and interpretation. A student, for instance, might become better at identifying the mathematics within a contextual situation without showing an equivalent improvement in evaluating the reasonableness of a final solution.

### **Proposed Data Analysis**

Analysis could begin with descriptive statistics to provide an overview of students' mathematical literacy performance before and after instruction. Means and standard deviations would show the general pattern of scores and provide an initial indication of differences within and between the two groups.

Inferential analysis would then depend on the study design, characteristics of the data, and whether the assumptions of the selected statistical procedures are satisfied. Paired-sample t-tests could be considered when examining pre-test to post-test changes within each group, while independent-sample t-tests could provide comparisons between groups where their use is statistically appropriate (Field, 2024). Effect sizes, including Cohen's *d*, would complement significance testing by indicating the magnitude of observed differences (Cohen, 1988; Field, 2024).

Because the proposed design uses intact classes rather than individual random assignment, baseline differences require particular attention. The pre-test should not be treated simply as another outcome measure; it also provides information about whether the two groups begin from comparable levels of mathematical literacy. The eventual analytical strategy should take such initial differences into account when estimating the relationship between instructional condition and post-intervention performance.

These procedures describe one possible route for testing the framework rather than a methodology that has already been implemented. No participants have been assigned, no intervention data are presented, and no statistical evidence of effectiveness is claimed in this conceptual paper. The purpose of outlining the design is to show how the relationships proposed in the framework could later be subjected to empirical examination.

## Discussion

### *Metaverse-Based Learning and Mathematical Literacy*

The value of a metaverse environment for mathematics education cannot be explained simply by the presence of immersive technology. Students may enter a visually rich virtual world without necessarily engaging in meaningful mathematical thinking. The more important issue is what they are asked to do once they are there. When an activity requires students to examine relationships, make mathematical choices, try different approaches, and use the results to resolve a contextual problem, the virtual environment becomes a setting for mathematical activity. Minecraft Education is understood in this framework in precisely this way: it provides conditions in which particular forms of mathematical learning may take place rather than functioning as a source of learning in its own right.

This interpretation extends previous discussions of immersive and metaverse-based education. Existing studies have reported potential benefits in areas including engagement, collaboration, and learning outcomes (Dwivedi et al., 2022; Geng & Su, 2024; Tlili et al., 2022). Such findings are useful, but mathematical literacy raises a more specific question. Being engaged in a virtual lesson or collaborating successfully with classmates does not necessarily mean that a student can recognise the mathematics embedded in a contextual situation or interpret the meaning of a mathematical result. The present framework brings these strands together by considering how immersion, interaction, collaboration, and visualisation might create conditions in which students actually use mathematics.

The distinction becomes clearer when mathematical literacy is considered through formulation, employment, and interpretation (OECD, 2023). Imagine, for example, a virtual task in which students have to design a structure under particular dimensional constraints. They first need to decide which features of the situation are mathematically relevant and represent them in a workable form. Mathematical concepts and procedures are then needed to develop the structure. Once a solution has been produced, students must determine whether it satisfies the original conditions. The virtual activity is educationally relevant because of this sequence of mathematical decisions, not merely because the task occurs in an immersive space.

The framework consequently places emphasis on the relationship between technological possibilities and mathematical activity. Immersion may situate students within a problem, interaction may allow them to test ideas by manipulating objects, collaboration may expose

them to alternative reasoning, and visualisation may make relationships easier to examine. None of these features guarantees improved mathematical literacy. Their contribution depends on whether the learning task uses them in ways that encourage students to formulate, employ, and interpret mathematics.

### ***Learning Processes Linking Metaverse Affordances and Mathematical Literacy***

A key issue raised by the framework concerns what occurs between experiencing a metaverse environment and developing mathematical literacy. Student engagement, spatial reasoning, and mathematical problem-solving are proposed as three processes that may help explain this relationship. Their inclusion moves the argument beyond a simple comparison between technology use and achievement by directing attention to what students experience and do while learning.

Student engagement represents one part of this explanation. Metaverse activities can position students as participants in a task rather than simply observers of a representation. A learner may need to move through a virtual space, alter an object, make a decision, or work towards a visible objective. These actions can encourage active participation, although activity alone should not be confused with mathematical engagement. Bond et al. (2021) associate engagement with learning in technology-supported environments, but its relevance here is more specific. Students who remain involved in a mathematical task have continuing opportunities to reconsider an approach, explain a decision, respond to difficulty, and persist with a problem. Engagement is therefore viewed as supporting the conditions under which mathematical thinking can continue rather than as the intended outcome of metaverse use.

Spatial reasoning offers a different connection. Geometry, measurement, coordinates, and other spatially oriented mathematical content often require students to understand relationships that can be difficult to communicate through a single static representation. Research has demonstrated associations between spatial reasoning and mathematics performance (Hawes et al., 2022; Lowrie et al., 2023). Within a three-dimensional environment, students may be able to move around a construction, inspect it from another position, alter a dimension, or observe how one change affects other features. Such experiences could provide additional ways of reasoning about spatial and mathematical relationships. The important proposition is not that three-dimensional visualisation automatically improves mathematical literacy, but that it may provide experiences that support the reasoning required in particular mathematical tasks.

Mathematical problem-solving is perhaps the most direct connection with mathematical literacy. Contextual problems often require students to determine for themselves which information matters and which mathematical approach is appropriate (OECD, 2023). A Minecraft Education task can be designed without prescribing the procedure that students must follow. For example, learners may know what they need to construct but have to decide whether measurement, geometric relationships, coordinates, ratios, or a combination of these ideas will help them achieve it. Mathematics then becomes a resource for resolving the situation rather than an operation performed because the teacher has already identified the required procedure. These three processes are likely to overlap during learning. A student who remains engaged with a difficult construction may spend longer examining its spatial properties and testing alternative solutions. A clearer understanding of a spatial relationship may change the strategy used to solve the problem. Working through the problem may, in turn, lead to further interaction with objects or discussion with classmates. Engagement, spatial reasoning, and problem-

solving are therefore better understood as potentially interacting aspects of mathematical activity than as three independent consequences of technology use. How strongly they are related, and whether they actually mediate changes in mathematical literacy, cannot be established by the present conceptual paper and remains a question for empirical investigation.

### ***Theoretical Contribution of the Framework***

The main conceptual distinction developed in this paper is between what the technology affords, what students do while learning, and the mathematical outcome of interest. Separating these elements is important because claims about educational technology can otherwise move too quickly from the availability of a technological feature to an assumption of improved learning.

Constructivist learning theory helps explain the middle part of this relationship. Students are expected to develop mathematical understanding through activity, exploration, interaction, and the negotiation of meaning rather than through passive exposure to information. Technology-mediated learning provides a complementary explanation by drawing attention to the possibilities that a particular environment creates for interaction among learners, tasks, content, and representations (Bower, 2023). Together, these perspectives suggest that technological features acquire educational significance through the learning experiences they enable.

The relationship proposed in this paper can be summarised as:

Metaverse learning affordances → Learning processes → Mathematical literacy

The first part of the pathway concerns immersion, interaction, collaboration, and visualisation. These describe possibilities associated with the learning environment. The second concerns student engagement, spatial reasoning, and mathematical problem-solving, which represent ways in which students may engage with mathematical activity. The final component is mathematical literacy, expressed through students' ability to formulate, employ, and interpret or evaluate mathematics in context.

This arrangement also clarifies the position of geometry, measurement, coordinates, and ratios. They are not explanatory variables within the model. Rather, they provide mathematical contexts in which the proposed relationships can be observed. A similar framework could potentially be examined through other content areas, provided that the activities require students to make decisions about how mathematics should be used in a meaningful situation. The conceptual emphasis remains on the processes of mathematical literacy rather than on any single mathematical topic.

### ***Implications for Mathematics Education***

The framework has practical implications for how metaverse-based mathematics activities are designed. The first concerns task design. Placing students inside Minecraft Education is not enough. A sophisticated virtual construction may be visually impressive while requiring very little mathematical thought. If mathematical literacy is the intended outcome, the task itself must create a genuine need for mathematics.

For example, rather than asking students simply to reproduce a structure from a completed model, a teacher might specify constraints involving dimensions, position, available space, or proportional relationships. Students would then have to determine how those conditions can be represented mathematically and decide which concepts are useful. The difference is significant: in the first activity, mathematics may be incidental; in the second, it becomes necessary for completing the task.

Teachers also remain central to the learning process. An immersive environment may make relationships visible, but students may not automatically recognise their mathematical significance. Teacher questioning can direct attention towards why a particular measurement was selected, whether another strategy would work, or whether a completed construction actually satisfies the original conditions. Discussion after an activity can similarly encourage students to connect actions performed in the virtual environment with formal mathematical concepts. The teacher's role therefore changes in emphasis rather than disappearing: guidance is needed to connect experience with mathematical interpretation.

A further implication concerns alignment between activities and the intended mathematical-literacy processes. A task designed around formulation should require students to identify the mathematics within a situation rather than provide the mathematical representation in advance. A task emphasising employment should give learners decisions to make about mathematical strategies or representations. Interpretation requires students to return to the context and explain whether their result is sensible or adequate. Designing with these distinctions in mind offers a practical way to prevent metaverse activities from becoming technologically engaging but mathematically superficial.

Collaboration also needs purposeful design. Asking students to occupy the same virtual environment does not necessarily result in productive mathematical discussion. Collaborative tasks should create reasons for learners to explain an approach, compare possible solutions, justify a decision, or resolve disagreement. In this sense, the quality of interaction matters more than the simple presence of multiple participants.

### ***Directions for Empirical Validation***

The relationships discussed in this paper remain propositions. No conclusion can yet be drawn that Minecraft Education, or metaverse-based learning more broadly, improves mathematical literacy. Empirical investigation is necessary to determine whether the proposed pathway is supported when the framework is implemented with students.

The quasi-experimental approach outlined earlier provides one possible starting point. Pre-test and post-test assessment could establish whether mathematical-literacy performance changes over an instructional period and whether patterns differ between metaverse-based and conventional learning conditions. Examining only the overall outcome, however, would test just part of the framework.

A fuller empirical investigation would also examine the proposed learning processes. If students in the metaverse condition demonstrate stronger mathematical-literacy outcomes, it would be useful to determine whether changes in engagement, spatial reasoning, or mathematical problem-solving accompany that difference. Conversely, if no substantial improvement is observed, examining these processes could help identify where the proposed

pathway fails to operate. Students might, for example, find the environment engaging without engaging deeply in mathematical problem-solving, or visualisation might support spatial reasoning without producing comparable changes in other dimensions of mathematical literacy. The Malaysian lower secondary context is particularly important for such validation because the present framework is intended for this educational setting while its proposed relationships have not yet been established empirically with Malaysian lower secondary students. Future research should consequently move beyond asking only whether metaverse-based instruction is effective. It should also examine which affordances students actually use, which learning processes are activated during mathematical activities, and how those processes relate to formulation, employment, and interpretation.

Such evidence would make it possible to refine the framework rather than merely confirm or reject it as a whole. Some proposed relationships may prove stronger than others, and their importance may vary according to the mathematical content, task design, students, or classroom conditions. Empirical validation should therefore be viewed not simply as a test of whether Minecraft Education “works,” but as an investigation of when, how, and through which learning processes an immersive environment may contribute to mathematical literacy.

## Conclusion

Mathematical literacy involves more than knowing how to perform mathematical procedures correctly. Students must also be able to recognise when mathematics is useful, determine how their knowledge can be applied, and make sense of a solution within the situation from which the problem arose. Developing these abilities requires learning experiences that give students opportunities to use mathematics purposefully rather than simply practise procedures in familiar forms.

This paper has considered how metaverse-based learning might provide such opportunities. The proposed framework separates the features offered by the learning environment from the learning processes students experience and the mathematical outcome the framework seeks to support. Immersion, interaction, collaboration, and visualisation describe what a metaverse environment can offer learners. Their educational significance, however, depends on how students respond to and work within those conditions. Student engagement, spatial reasoning, and mathematical problem-solving are therefore positioned as processes through which these affordances may contribute to mathematical learning.

Mathematical literacy remains the central outcome of this relationship. Following the PISA perspective, it is understood through students' ability to formulate situations mathematically, employ mathematical concepts and procedures, and interpret or evaluate mathematical outcomes in context (OECD, 2023). Geometry, measurement, coordinates, and ratios offer possible settings in which students can practise these processes, but they are not treated as separate constructs within the framework.

Constructivist and technology-mediated perspectives provide the theoretical reasoning behind these relationships. Together, they suggest that the educational value of Minecraft Education cannot be attributed simply to its immersive or technological characteristics. What is more important is whether the environment creates meaningful opportunities for students to explore mathematical relationships, interact with representations, discuss possible approaches, and use mathematics to resolve contextualised problems. In this sense, the technology provides the

setting and possibilities for learning, while the mathematical activity students undertake within that setting remains central.

The framework should nevertheless be interpreted with appropriate caution. This paper is conceptual and does not establish that learning through Minecraft Education improves mathematical literacy. The proposed relationships have yet to be tested with students, and their strength may depend on factors such as task design, mathematical content, classroom implementation, and the ways learners use the virtual environment. The quasi-experimental approach outlined in this paper offers one possible starting point for investigating these relationships among Malaysian lower secondary students.

The contribution of the framework is therefore explanatory rather than evidential at this stage. It offers a way of examining what may occur between the use of an immersive learning environment and the development of mathematical literacy, rather than treating technology use and learning outcomes as directly connected. Future empirical work can determine whether the proposed relationships are supported, how engagement, spatial reasoning, and mathematical problem-solving operate within them, and whether similar patterns emerge across different mathematical topics and educational settings. Such investigation would help establish not simply whether metaverse-based mathematics learning is effective, but under what conditions and through which learning processes it may support students in using mathematics meaningfully.

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- Acknowledgements:** The authors gratefully acknowledge the support provided by Universiti Malaysia Sabah (UMS) in facilitating this conceptual work. Appreciation is extended to all individuals who contributed directly or indirectly through their expertise, constructive feedback, and valuable insights. Their contributions have been instrumental in strengthening the scholarly quality of the manuscript.
- Funding Statement:** No Funding
- Conflict of Interest Statement:** The authors declare that there is no conflict of interest regarding the publication of this paper. All authors have contributed to this work and approved the final version of the manuscript for submission to the International Journal of Education, Psychology and Counselling (IJEPC).
- Ethics Statement:** This article is a conceptual study based on published literature and does not involve human participants, identifiable personal data, or primary data collection. Therefore, institutional ethics approval and informed consent were not required for the present paper. Any future empirical validation involving students will be subject to the relevant institutional and school-level ethical approval procedures, parental or guardian consent where applicable, student assent, confidentiality protections, and secure data management.
- Author Contribution Statement:** All authors contributed to the conceptual development and preparation of this manuscript. Diana Hassan led the conceptualisation, framework development, literature synthesis, project administration, and preparation of the original draft. Assis Kamu contributed to literature identification, synthesis, and validation of the conceptual relationships. Ho Chong Mun provided supervision, theoretical guidance, quality assurance, and critical review. Aaron Ismanto Anggang contributed to the proposed methodology for future empirical validation, framework refinement, and manuscript review and editing. All authors reviewed and approved the final manuscript.
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