Journal of Frontiers in Multidisciplinary Research

The Urgency of Metaverse-Based Science Learning for Biological Classification in Junior High School: Rationale, Design Framework, and Classroom Implementation

Ihza Sania Risti [1*], Abdulkadir Rahardjanto [2], Iin Hindun [3]
[1-3] Master of Biology Education, Postgraduate Program, Universitas Muhammadiyah Malang, Indonesia

* Corresponding Author: **Ihza Sania Risti**

Article Info

E-ISSN: 3050-9726
P-ISSN: 3050-9718
Volume: 05
Issue: 02
July - December 2024
Received: 14-08-2024
Accepted: 16-09-2024
Published: 18-10-2024
Page No: 127-135

Abstract
Biological classification is a foundational topic in junior high school science because it organizes biodiversity knowledge and supports later learning in ecology, evolution, and health. Yet, many students struggle with taxonomic reasoning, dichotomous keys, and the use of observable traits to justify categorization, partly because classroom learning often relies on static images and memorization. At the same time, the rapid diffusion of immersive and social digital environments has made the educational metaverse a realistic option for creating authentic, interactive, and collaborative experiences. This article argues that metaverse-based learning is urgent for the topic of living-things classification in Indonesian junior high schools, and it proposes a practical design framework and implementation model. Using educational design research principles, we synthesize evidence from virtual reality and metaverse literature on presence, embodiment, interactivity, and cognitive-affective learning processes to derive design requirements for conceptually difficult biology content. The results of this study are presented as a metaverse learning blueprint that aligns with inquiry-oriented pedagogy (5E and scientific practices), includes safety and equity considerations, and provides ready-to-use lesson sequences, assessment instruments, and classroom management strategies. We also offer a risk-mitigation approach to manage cognitive load, cybersickness, privacy, and device constraints through pre-briefing, guided exploration, structured collaboration, and post-immersion debriefing. This paper contributes a structured rationale and an implementation-ready model that can be adapted by science teachers and schools while providing a research agenda for rigorous evaluation of learning outcomes, engagement, and digital citizenship in metaverse-based biology instruction.

DOI: https://doi.org/10.54660/.IJFMR.2024.5.2.127-135

Keywords: Metaverse; Immersive Virtual Reality; Science Education; Biological Classification; Junior High School; Inquiry Learning

Introduction

Classification of living things is not merely a list of kingdoms and Latin names; it is a way of reasoning about similarity, difference, and evidence. In junior high school, students are expected to use observable traits to sort organisms, interpret classification schemes, and apply dichotomous keys or simple identification guides. These competencies support broader scientific literacy because they train students to justify claims with data, recognize patterns, and communicate explanations in a structured manner.

Despite its importance, classification is frequently taught as memorization. Many students can recite categories but cannot explain why a mushroom is not a plant or why certain organisms are grouped together. Research in biology education repeatedly shows that misconceptions and fragmented prior knowledge can persist unless instruction triggers conceptual change and makes students actively revise their mental models (Aleknavičiūtė *et al*., 2023; Posner *et al*., 1982) [1, 20]. In Indonesia, evidence from diagnostic-test studies suggests that misconceptions also occur in the classification topic among junior high school students, indicating a need for learning experiences that go beyond textbooks (Amalia *et al*., 2023) [3].

Meanwhile, education is experiencing a new wave of spatial and social computing. The term metaverse refers to persistent multiuser environments that blend physical reality with digital virtuality, often mediated by avatars, immersive displays, and networked interaction (Dionisio *et al*., 2013; Mystakidis, 2022) [6, 18]. Educational researchers have proposed definitions, roles, and research issues for metaverse-based education, including how artificial intelligence, virtual reality (VR), and augmented reality (AR) can extend teaching and learning beyond the limits of time and space (Hwang & Chien, 2022; Lin *et al*., 2022) [8].

The urgency of metaverse-based science learning is particularly strong for biological classification because the topic benefits from interaction with diverse, realistic specimens and from repeated practice in observation and comparison. In many schools, direct biodiversity exploration is constrained by limited laboratory collections, safety and time constraints, and unequal access to outdoor field experiences. A metaverse environment can function as a virtual biodiversity museum or simulated ecosystem where students observe organisms from multiple angles, manipulate features, and collaboratively debate classifications in real time.

This article addresses two questions: (1) Why is metaverse-based science learning urgent for the topic of living-things classification in junior high school? and (2) How can it be implemented in a realistic and safe way in Indonesian classrooms? To answer these questions, we synthesize peer-reviewed evidence about immersive learning mechanisms and translate it into a design and implementation blueprint that teachers can apply. Unlike purely conceptual commentaries, this paper provides actionable outputs: an alignment table between metaverse affordances and learning objectives, a lesson flow for SMP, assessment recommendations, and practical risk-mitigation strategies.

In the Indonesian junior high school (SMP) context, classification is commonly introduced in Grade 7 within the broader strand of biodiversity and ecosystem understanding. Teachers must balance curriculum coverage with limited instructional time, and many classrooms rely on printed worksheets or slide presentations. Students' difficulties are amplified when learning resources are abstract or when learning activities do not require students to make and defend classifications using evidence. Consequently, students may treat classification as a set of arbitrary labels rather than a reasoning tool for organizing biological information.

Digital transformation in schools offers both an opportunity and a challenge. On one hand, students are increasingly familiar with interactive digital media and game-like experiences. On the other hand, classrooms face unequal access to devices, internet bandwidth, and teacher preparation. A realistic proposal for metaverse-based instruction must therefore be sensitive to school diversity. In this paper, metaverse learning is treated as a flexible ecosystem of technologies and practices rather than a single expensive platform: it may be implemented through immersive headsets, computer laboratories, or even mobile devices with simplified 3D environments, as long as the learning design preserves interaction, collaboration, and evidence-based reasoning.

Literature Review

Conceptualizing the educational metaverse

Although the term metaverse is used inconsistently across public discourse, scholarly literature highlights several stable characteristics. First, metaverse environments are persistent and multiuser, enabling repeated access and shared experiences. Second, users often inhabit the environment through avatars or digital identities, supporting embodied and social interaction. Third, metaverse ecosystems typically integrate immersive realism, communication, and a sense of place, even when accessed through non-immersive devices such as desktop computers (Dionisio *et al*., 2013; Girvan, 2018) [6, 7].

Mystakidis (2022) [18] describes the metaverse as a post-reality universe that merges physical reality with digital virtuality in persistent multiuser environments and emphasizes multisensory interaction. In educational settings, metaverse platforms range from fully immersive VR experiences to browser-based 3D worlds that support collaboration, content creation, and simulation. Importantly, educational benefits depend less on the novelty of the platform and more on the pedagogical design and the alignment between affordances and learning goals (Dalgarno & Lee, 2010; Radianti *et al*., 2020) [5, 22].

Hwang and Chien (2022) propose that research on metaverse in education should address definition clarity, pedagogical roles, and practical challenges such as data privacy, ethical issues, and the integration of AI. Similarly, Kye *et al*. (2021) [11] map the metaverse into categories such as augmented reality, mirror worlds, lifelogging, and virtual worlds, and discuss both the educational potential and risks related to privacy and maladaptation. These perspectives indicate that metaverse-based learning should be planned with governance, safety, and digital citizenship as core design requirements, not optional add-ons.

Learning theories supporting metaverse-based science learning

Metaverse-based learning aligns naturally with constructivist and experiential learning perspectives, which emphasize that learners build knowledge through active exploration and reflection. Kolb's experiential learning cycle (concrete experience, reflective observation, abstract conceptualization, and active experimentation) provides a useful structure for designing immersive cycles where students explore a virtual ecosystem, reflect on observations, generalize classification rules, and apply them to new organisms (Kolb, 1984) [10].

However, open exploration alone is not sufficient. Instructional design research warns that minimal guidance can overload novice learners, especially when environments are complex (Kirschner *et al*., 2006) [9]. Therefore, metaverse environments require scaffolding: clear roles, structured tasks, prompts for noticing relevant traits, and supports for argumentation and evidence use.

Contemporary immersive-learning theory also highlights cognitive-affective mechanisms. The Cognitive Affective Model of Immersive Learning (CAMIL) proposes that immersion and interactivity influence learning through presence and agency, while also shaping interest, motivation, embodiment, and cognitive load (Makransky & Petersen, 2021). Empirical work suggests that immersion can increase presence and interest but may also increase extraneous cognitive load if design is not aligned with multimedia principles (Makransky *et al*., 2019; Petersen *et al*., 2022).

From an engagement perspective, the ICAP framework suggests that learning activities that involve active manipulation and constructive creation tend to yield stronger learning outcomes than passive reception (Chi & Wylie, 2014). Immersive VR is particularly promising for learning goals that require active engagement and practical application, as emphasized in recent systematic reviews (Conrad *et al.*, 2024) [24]. Therefore, metaverse-based classification learning should prioritize active observation, manipulation of specimens, and collaborative construction of classification arguments rather than mere virtual touring.

Evidence base: VR/metaverse effects on learning

Across decades of research, virtual environments have shown positive average effects on learning, but outcomes vary depending on instructional design and the type of learning objective. Merchant *et al.* (2014) [17] reported that virtual reality-based instruction (including games, simulations, and virtual worlds) generally improves learning outcomes in K-12 and higher education, with important moderator effects of design features such as feedback and collaboration. Radianti *et al.* (2020) [22] synthesize immersive VR applications and highlight that many studies focus on usability rather than learning outcomes, calling for stronger theory-driven design and evaluation.

Metaverse-focused syntheses also indicate promising but uneven evidence. Pradana and Elisa (2023) [21] review metaverse studies in education and identify themes related to applications, challenges, and underexplored issues such as teaching strategies and knowledge construction. Al Khateeb and Alotaibi (2024) [2] report a large average effect size for metaverse-related interventions across experimental studies from 2020–2023, suggesting that metaverse technologies can significantly enhance performance when used appropriately. Nevertheless, reviews caution that metaverse benefits are not automatic; they depend on pedagogical integration and context-sensitive implementation (Kye *et al.*, 2021; Hwang & Chien, 2022) [11, 8].

Why classification is a high-fit topic for metaverse learning

Biological classification requires learners to coordinate multiple forms of representation: visual morphology, ecological context, and symbolic category labels. Students often need repeated practice to distinguish superficial similarity from diagnostically relevant traits and to understand that scientific classification is based on shared characteristics and evolutionary relationships. Immersive environments can provide rich, manipulable representations of organisms, enabling learners to zoom, rotate, compare traits side-by-side, and observe behavior or habitat context that is difficult to capture in 2D images.

Metaverse spaces can also strengthen scientific practices that are central to classification learning: evidence collection, reasoning, and argumentation. In a shared virtual ecosystem, students can divide roles (observer, recorder, classifier, skeptic), collect trait data collaboratively, and defend classification decisions with explicit evidence. Such designs align with recommendations that immersive environments be used to support situated experiential learning while acknowledging constraints in classroom logistics (Schott *et al.*, 2024) [23].

Implementation constraints and ethical considerations

Metaverse initiatives in schools must address device availability, bandwidth, and equity. Many Indonesian junior high schools may not have sufficient head-mounted displays for all students. Designing a multi-access environment—supporting both immersive VR and desktop/mobile access—reduces exclusion and allows rotational station models. Additionally, privacy and safety risks require careful policy: minimal collection of biometric data, age-appropriate identity management, and clear norms for communication, respectful behavior, and intellectual property (Hwang & Chien, 2022; Kye *et al.*, 2021) [8, 11].

Finally, physiological comfort matters. Cybersickness and fatigue can undermine learning if sessions are too long or movement is poorly designed. Short sessions, optional locomotion modes (teleportation), and structured breaks are practical strategies to mitigate these risks. These concerns motivate the design principles and implementation model proposed in the next sections.

Presence, embodiment, and scientific meaning-making

Presence is commonly defined as the subjective sense of 'being there' in a mediated environment. In virtual worlds, presence can support attention and emotional engagement, which may increase willingness to persist in learning tasks. However, presence is not an educational goal by itself. It becomes valuable when it is tied to purposeful actions, such as comparing traits, collecting evidence, or testing a classification hypothesis.

Embodied interaction can support learning because it links perception and action. In classification tasks, students do not only read about traits; they inspect, rotate, and compare organisms, which may strengthen discrimination of relevant features. Yet, embodiment can also increase cognitive demands if controls are complex or if irrelevant movements distract from conceptual targets. Therefore, research recommends simple, consistent interaction patterns and guided attention prompts in immersive lessons (Makransky & Petersen, 2021; Petersen *et al.*, 2022) [14].

Measurement matters for both research and practice. Presence and related affective variables can be assessed with validated scales such as the multimodal presence scale, enabling teachers and researchers to monitor whether an immersive session supports or hinders learning (Makransky *et al.*, 2017; Makransky & Lilleholt, 2018) [16, 13]. Integrating short, low-burden measures into classroom pilots helps identify design problems early, such as excessive cognitive load or disorientation.

Social learning and collaboration in metaverse environments

One of the distinctive educational promises of the metaverse is multiuser collaboration. Unlike single-user VR apps, metaverse environments can host group inquiry where students coordinate observations and build shared explanations. Social presence and avatar-based interaction can increase participation and peer support, but they can also create off-task behavior if social features are not bounded by clear learning norms.

Design work on 3D virtual learning environments emphasizes that learning benefits arise when affordances are matched to tasks that require interaction and co-construction of knowledge (Dalgarno & Lee, 2010) [5]. For classification learning, collaborative tasks can be designed as evidence-based debates: one student proposes a classification, another challenges it by citing a contradictory trait, and the team negotiates a final decision. Such dialogic processes can externalize reasoning and make misconceptions visible for instructional intervention.

To keep collaboration productive, the learning design should include: role rotation, shared artifacts (e.g., a team classification board), time constraints, and explicit criteria for 'acceptable evidence'. Teachers can act as facilitators who monitor team talk and trigger deeper justification when students rely on superficial cues. This approach also supports inclusive participation by assigning structured speaking turns and varied responsibilities (observer, recorder, presenter).

Assessment, learning analytics, and feedback

Classification competence can be assessed through multiple evidence sources. A simple multiple-choice test may capture declarative knowledge (e.g., knowing category names) but will not capture taxonomic reasoning. Performance assessments, such as using a dichotomous key to identify an organism or producing a concept map of taxonomic relationships, better represent the targeted competencies.

In metaverse environments, assessment can be strengthened through embedded logs that record actions: which traits students inspected, how many classifications attempts they made, and how they responded to feedback. While learning analytics can support formative assessment, it must be implemented ethically, minimizing personally identifiable data and avoiding biometric monitoring unless essential (Hwang & Chien, 2022) [8].

Feedback design is a key moderator of learning in virtual environments (Merchant *et al.*, 2014) [17]. For classification tasks, feedback should be explanatory rather than merely indicating correct/incorrect. Explanatory feedback can point to the specific trait that distinguishes two categories (e.g., spores vs. seeds), encouraging students to align decisions with evidence and helping to correct misconceptions.

Summary of literature-derived design requirements

Across the reviewed literature, five design requirements consistently emerge for effective metaverse-based science learning: (1) align immersive affordances with clear learning objectives; (2) scaffold inquiry with prompts, roles, and structured tasks; (3) manage cognitive load through simplicity and short sessions; (4) support collaboration with shared artifacts and norms; and (5) ensure safety, equity, and privacy through policy and platform configuration. These requirements guide the design and implementation blueprint reported below.

Platforms and continuity with earlier virtual worlds

Educational use of 3D virtual environments predates the recent 'metaverse' label. Multi-user virtual environments and virtual worlds have been used for simulation, inquiry, and social learning for years. Merchant *et al*. (2014) [17] discuss how virtual worlds such as Second Life have supported collaborative learning and experiential activities, highlighting that educational value depends on instructional design rather than branding. This continuity is important for schools: metaverse-based classification learning can be implemented using existing, stable virtual world technologies as long as they allow shared spaces, interaction with objects, and teacher supervision.

Recent educational discussions emphasize that the metaverse is best understood as an ecosystem with multiple access routes rather than a single device-dependent solution (Kye *et al*., 2021; Lin *et al*., 2022) [11]. For junior high schools, this implies that early adoption should prioritize platforms that are lightweight, accessible, and safe for minors. Even if a school cannot provide headsets, a 3D web environment that supports avatars, voice/text chat, and interactive specimens can still enable the inquiry and collaboration processes targeted in this paper.

Method

This study uses an educational design research (EDR) orientation to produce a practical learning design while remaining grounded in theory and evidence. EDR is appropriate because metaverse-based instruction involves complex interactions among pedagogy, technology, classroom context, and learner characteristics. The method therefore emphasizes iterative design decisions and an explicit mapping from theory to design features rather than a single isolated experiment.

Design artifact. The central artifact is a metaverse-based learning unit for Grade 7 biological classification. The unit includes: (a) a scenario narrative, (b) learning objectives and success criteria, (c) metaverse environment specifications, (d) teacher facilitation scripts, (e) student worksheets and reflection prompts, and (f) assessment rubrics. Two author-created figures are used to communicate the framework and the instructional flow. Two tables are used to show alignment and lesson planning.

Phase 1: Needs and context analysis.

We synthesize evidence on common student difficulties in classification and on the conditions of SMP classrooms. At the concept level, classification difficulties often involve overreliance on surface features, confusion between organism groups, and limited ability to justify classification decisions with traits or key steps. At the context level, constraints include limited specimen collections, uneven access to digital devices, and limited time for fieldwork. Published misconception diagnostics provide a concrete starting point for designing conceptual change triggers (Amalia *et al*., 2023) [3].

Phase 2: Theory-to-design translation.

We translate metaverse affordances and immersive learning theory into design principles. From definitions of virtual worlds and metaverse, we derive requirements for persistence (repeatable access), identity (team-based avatars), and interaction (trait manipulation, comparison tools) (Dionisio *et al*., 2013; Girvan, 2018; Mystakidis, 2022) [6, 7, 18]. From CAMIL and related work, we derive psychological affordances (presence and agency) and control factors to manage cognitive load (Makransky & Petersen, 2021; Petersen *et al*., 2022) [14]. From instructional design syntheses, we derive the need for feedback, structured collaboration, and teacher orchestration (Merchant *et al*., 2014; Radianti *et al*., 2020) [17, 22].

Phase 3: Development specification.

The proposed metaverse environment is described at three fidelity levels to support different school capacities: (Level A) immersive VR with head-mounted displays; (Level B) semi-immersive 3D on large screens with game controllers; and (Level C) desktop/mobile 3D web-based access. All levels share the same learning tasks and scaffolds to ensure pedagogical equivalence. The environment is organized into zones: a virtual biodiversity museum (specimen gallery), biome simulations (habitat context), an inquiry hub (instructions and resources), and collaboration rooms (debate and concept mapping).

Phase 4: Pilot implementation plan.
The unit is designed for five meetings with a blended structure: a short metaverse session (10–20 minutes per group) combined with off-device activities such as trait worksheets, concept mapping, and teacher-led discussions. A rotation model is recommended when devices are limited. Teachers are provided with facilitation scripts for pre-briefing, in-world prompts, and debriefing questions. Classroom management includes group roles, timekeeping, and norms for safe movement and respectful communication.

Phase 5: Evaluation plan and instruments.
For future pilots, we recommend a mixed-method evaluation design. Quantitative measures include: (a) a concept test focusing on classification reasoning and dichotomous key steps; (b) rubric scores for a performance task (identifying and justifying classification); and (c) short scales for presence and perceived cognitive load (Makransky *et al.*, 2017; Makransky & Lilleholt, 2018) [16, 13]. Qualitative measures include observation notes of collaboration, student reflection responses, and teacher interviews about feasibility and perceived value. Triangulating these sources supports both effectiveness evaluation and iterative improvement.

Data analysis plan for future pilots.
In pilot studies, learning gains can be estimated using normalized gain or pre/post difference scores on the concept test, alongside rubric-based performance outcomes. To understand mechanisms, correlations among presence, cognitive load, and learning outcomes can be explored, reflecting prior work that models how immersive features influence learning through affective and cognitive pathways (Makransky & Lilleholt, 2018; Petersen *et al.*, 2022) [13]. Qualitative data (student reflections and observation notes) can be coded for themes such as evidence use, misconception repair, and collaboration quality, supporting iterative refinement of the learning design.

Results and Discussion

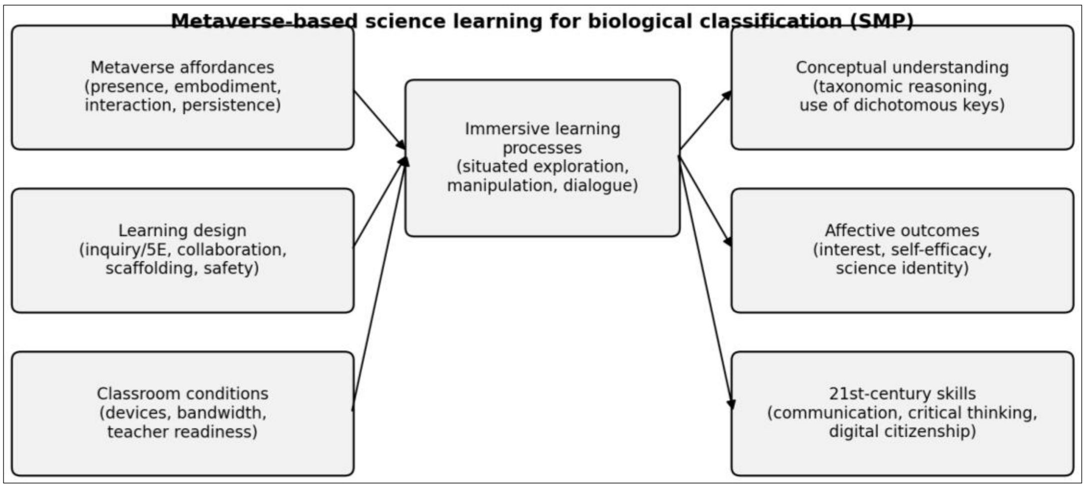

Fig 1: Conceptual framework linking metaverse affordances, learning design, and outcomes for classification learning (author-created).

Design outputs and curriculum alignment
The results of this study are presented as a design blueprint rather than statistical findings. The blueprint defines: learning objectives, metaverse affordance alignment, instructional flow, and assessment plans. The design assumes a junior high school classification unit that emphasizes evidence-based reasoning and the use of dichotomous keys, supported by collaborative inquiry activities.
Table 1 maps metaverse affordances to specific learning objectives and activities. The mapping emphasizes that each affordance must serve a learning purpose. For example, presence is used to improve attention to organism traits, and persistence is used to support repeated practice and revision of classification decisions across sessions.

Design principles for metaverse-based classification learning
From the literature synthesis, we propose eight operational design principles for the unit:
Trait-first design: All tasks begin with observing traits before naming categories.
Compare-and-contrast: Students compare at least two organisms before deciding.
Guided key use: A virtual dichotomous key tool scaffolds reasoning step-by-step.
Evidence talk: Teams justify classifications using explicit trait evidence.
Short immersive bursts: Immersion is limited to avoid fatigue and overload.
Debrief for conceptual change: Post-immersion discussions and concept maps consolidate learning.
Multiple access modes: Equivalent tasks across HMD, desktop, and mobile.
Ethical-by-design: Privacy, respectful communication, and safety norms are embedded.

Learning scenario: "Virtual Biodiversity Quest"
The learning unit uses a narrative to provide purpose and structure. Students are positioned as junior taxonomists supporting a conservation project that needs an evidence-based inventory of organisms. The narrative is not purely decorative; it motivates repeated classification practice and provides a reason to document evidence. Students work in teams of four with rotating roles: Observer (inspects traits), Recorder (fills the trait table), Classifier (applies the key), and Skeptic (challenges decisions and checks evidence).
During immersion, students explore several virtual zones. In the specimen gallery, they can rotate organisms and inspect trait labels that can be toggled on/off (to support fading of scaffolds). In biome zones, organisms appear in context,

allowing students to differentiate habitat cues from diagnostic traits. An inquiry hub provides the virtual dichotomous key and short micro-lessons (30–60 seconds) that can be accessed on demand, reducing the need for long in-world lectures.

The unit includes deliberately challenging organisms that are known to trigger misconceptions, such as fungi, algae-like protists, and animals with plant-like camouflage. These near-miss cases create productive cognitive conflict. Teachers can use them to ask refutational questions (e.g., 'If it is a plant, where are the seeds?') and guide students to revise their classification based on evidence (Posner *et al*., 1982) [20].

Instructional flow and classroom orchestration

Figure 2 summarizes the recommended flow: pre-brief, immersion, debrief, and assessment/reflection. Pre-briefing is essential for safety and learning. It clarifies goals, teaches basic controls, and activates prior knowledge with a short diagnostic prompt. Debriefing is equally essential because it helps students transform immersive experience into conceptual understanding through explanation, comparison, and abstraction (Kolb, 1984) [10].

Table 2 outlines a five-meeting lesson plan that is feasible for SMP schedules. The plan is designed for blended learning with rotational stations. When only a few devices are available, each group spends 10–15 minutes in the metaverse while other groups work on supporting tasks, such as identifying local organisms from pictures, building a concept map, or practicing a paper-based dichotomous key. This structure ensures all students remain engaged and reduces idle time.

Assessment products and rubrics

The unit recommends two core assessments:

1. A performance task: identify three unknown organisms using a dichotomous key and provide a written justification citing at least three traits.
2. A concept map task: construct a map linking major groups (plants, animals, fungi, protists, bacteria) with defining traits and example organisms.

Rubrics emphasize evidence use, correct key navigation, clarity of reasoning, and accurate representation of relationships.

In addition, short reflective prompts capture students' metacognition and digital citizenship. For example: 'Which trait was most useful today and why?', 'What mistake did your team correct after discussing evidence?', and 'How did you communicate respectfully in the virtual space?' These prompts help teachers identify misconceptions and support the formation of responsible behavior in avatar-based environments.

Discussion: Why the model is urgent and how it works

1. Conceptual understanding through situated and embodied evidence.

Classification is a topic where 'seeing' and 'comparing' matter. Metaverse environments provide repeated exposure to diverse specimens, enabling learners to inspect traits that are often missing from textbook images. When designed for active manipulation and explanation, such environments can support the presence-and-agency mechanisms described in CAMIL (Makransky & Petersen, 2021; Petersen *et al*., 2022).

2. Managing cognitive load to protect learning.

Research shows that adding immersion can increase presence but also reduce learning if cognitive load rises and attention is diverted (Makransky *et al*., 2019) [15]. Our design addresses this by keeping immersive sessions short, simplifying controls, and focusing attention with prompts and trait checklists. The rotation model also reduces exposure time and provides breaks, which can mitigate discomfort and fatigue. Finally, debriefing tasks (concept mapping and written justification) reduce the risk that students remember the experience but not the scientific meaning.

3. Collaboration and argumentation as learning engines.

The metaverse supports social learning, but learning gains depend on structured collaboration. Role-based team inquiry, shared classification boards, and evidence rules transform social interaction into scientific argumentation. This design aligns with findings that feedback and collaboration are key moderators in virtual learning environments (Merchant *et al*., 2014) [17] and with calls for practical, teacher-informed frameworks for K-12 VR integration (Schott *et al*., 2024) [23].

4. Feasibility and equity in real schools.

Metaverse initiatives can widen inequality if they assume expensive hardware. The proposed three-level access approach allows schools to adopt metaverse learning gradually. Even desktop-based 3D environments can support key learning benefits if they enable interaction, comparison, and collaboration, consistent with 3D VLE affordance models (Dalgarno & Lee, 2010) [5] and VR education reviews emphasizing design and pedagogy (Radianti *et al*., 2020) [22].

5. Ethics, privacy, and governance.

Metaverse learning involves digital identity and potentially sensitive data. Therefore, schools should prioritize platforms that allow pseudonymous student accounts, restricted access, and minimal data collection. Teachers should explicitly teach norms for respectful communication, avoid sharing personal data, and reflect with students on how avatar-based interaction can shape behavior. These practices respond to research concerns about privacy and identity in metaverse education (Hwang & Chien, 2022; Kye *et al*., 2021) [8, 11].

Limitations and future research

This study provides a theory- and evidence-informed blueprint, but it does not report new experimental results. Implementation and impact will vary by platform, teacher readiness, and school infrastructure. Future empirical research should test the blueprint through iterative classroom pilots, measuring conceptual understanding, transfer to local biodiversity contexts, and long-term retention. Researchers should also compare access modes (HMD vs. desktop) and investigate how specific scaffolds (trait prompts, key tools, feedback types) interact with cognitive load and presence. Finally, future work should examine equity outcomes and develop guidance for inclusive participation for students with diverse needs.

Technical and logistical specification

To help teachers translate the blueprint into practice, we specify minimal technical features required for the metaverse environment. First, the platform must allow multiuser sessions with teacher control (start/stop, teleport groups, mute/voice settings) and a private classroom space. Second, it should support interaction with objects (rotate, zoom, highlight traits) and display shared artifacts (team boards, sticky notes, or shared canvases). Third, it should allow export or capture of student products (screenshots of classification boards, logs of key choices) to support assessment and evidence collection.

For schools with limited bandwidth, the design should minimize heavy real-time rendering by using optimized 3D models and limiting simultaneous users per room. A practical option is to run multiple small sessions (e.g., 6–8 students per room) and rotate groups. Teacher facilitation is simplified when the environment provides clear visual markers (e.g., colored zones, numbered specimens) and a consistent interaction scheme across objects.

Teacher competencies and professional development needs

Implementing metaverse-based science learning requires more than technical operation. Teachers need competencies in (a) inquiry facilitation, (b) classroom orchestration with stations, (c) formative assessment using student artifacts, and (d) digital citizenship and safety management. Short professional development can focus on: how to run pre-brief and debrief routines, how to use role cards to structure collaboration, and how to interpret evidence from student work. Because many studies note that VR implementations often overemphasize usability and underemphasize learning outcomes (Radianti *et al*., 2020) [22], teacher training should explicitly connect technology features to learning objectives and assessment criteria.

Risk mitigation and safety protocol

Based on prior concerns in immersive learning research, we recommend a simple safety protocol. (1) Keep immersive sessions brief (10–15 minutes per student group), with seated or limited-motion experiences when possible. (2) Provide alternative access for students who experience discomfort (desktop mode or observer role). (3) Use teleportation or point-and-click navigation rather than continuous movement to reduce cybersickness. (4) Establish communication norms and moderation (no personal data sharing, respectful language, teacher-controlled room access). (5) Document and reflect after each session to improve routines and identify students who need additional support.

Practical implementation checklist

For quick adoption, schools can use the following checklist:

Learning objectives and success criteria are stated in student-friendly language.

Metaverse tasks require trait observation, comparison, and evidence-based justification.

Roles and collaboration rules are distributed and rotated.

Pre-brief covers goals, controls, and safety.

Debrief includes concept mapping and argumentation.

Assessment includes a performance task and rubric.

Privacy settings and account management follow school policy.

A backup plan exists (desktop access or offline alternative) for technical issues.

This checklist supports consistent implementation across diverse classroom conditions.

Table 1: Metaverse affordances mapped to junior high school classification learning objectives and activities.

Metaverse affordance	Instructional function	Classification learning objective	Example activity (SMP)
Presence & spatial immersion	Focus attention on organism traits; reduce abstraction	Identify and describe diagnostic traits across groups	Rotate specimens; zoom to view structures; label key traits
Embodiment & manipulation	Link perception and action to support discrimination	Compare organisms using evidence; avoid superficial cues	Side-by-side comparison; trait checklist completion
Multiuser social interaction	Enable peer explanation and argumentation	Justify classification decisions with trait-based reasoning	Role-based debate: proposer vs. skeptic with evidence rules
Persistence & revisitable spaces	Support repeated practice and revision	Apply dichotomous keys accurately over time	Return to specimens; redo key paths after feedback
Content creation / shared artifacts	Externalize thinking; make reasoning visible	Represent relationships among groups (concept mapping)	Team classification board; concept map built in-room

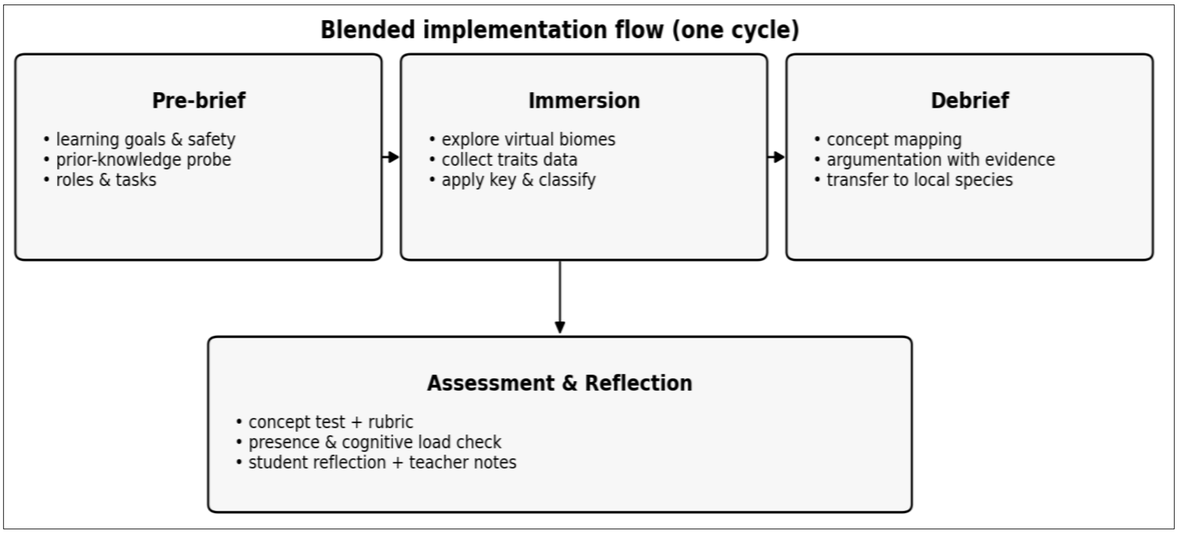

Fig 2: Blended implementation flow for a metaverse-based classification lesson cycle (author-created).

Table 2: Example five-meeting implementation plan for SMP (Grade 7) biological classification.

Meeting	Focus	Metaverse / station activity	Off-device activity	Assessment evidence
1	Preconceptions & basic traits	Orientation + specimen gallery: observe 6 organisms	Trait worksheet + quick diagnostic questions	Baseline concept check; observation notes
2	Using dichotomous keys	Guided key tutorial + 3 identification cases	Paper-based key practice + peer feedback	Key navigation rubric (formative)
3	Challenging cases (fungi, protists)	Biome exploration + near-miss organisms	Refutational prompts + concept map draft	Misconception repair notes; concept map draft
4	Argumentation & collaboration	Team debate room: classify 'mystery organism' set	Evidence-based explanation writing	Debate rubric; written justification
5	Transfer to local biodiversity	Virtual local-biome quest + documentation	Local species examples (photos) + final concept map	Posttest; final products portfolio

Conclusion

Metaverse-based science learning is urgent for the junior high school topic of biological classification because it can provide access to diverse, manipulable specimens and support collaborative evidence-based reasoning under constraints that often limit physical fieldwork and specimen availability. However, the metaverse should not be adopted as a novelty. Its educational value depends on theory-informed design, careful scaffolding, and ethical implementation.

This article contributes a practical blueprint for SMP classrooms: a framework linking metaverse affordances to classification learning outcomes, a blended lesson flow, and guidance for assessment and risk mitigation. By integrating experiential learning, inquiry pedagogy, and immersive learning theory, the model aims to enhance conceptual understanding while managing cognitive load and ensuring equity, privacy, and safety. The proposed approach offers a starting point for teachers and researchers to pilot, adapt, and rigorously evaluate metaverse-based biology instruction in real school contexts.

Beyond the classification topic, the same design logic can be extended to other junior high school biology themes that benefit from visualization and inquiry, such as ecosystems, human body systems, or environmental change. Nevertheless, classification is a strategic starting point because it builds foundational reasoning about biodiversity and evidence. Carefully designed metaverse learning can therefore contribute not only to content mastery but also to students' habits of scientific thinking and responsible participation in digital environments.

References

1. Aleknavičiūtė V, Lehtinen E, Södervik I. Thirty years of conceptual change research in biology: a review and meta-analysis of intervention studies. Educ Res Rev. 2023;41:100556. doi:10.1016/j.edurev.2023.100556
2. Al Khateeb A, Alotaibi H. The upsurge of the metaverse in educational settings: a meta-analysis study. Pegem J Educ Instr. 2024;14(3):62-75. doi:10.47750/pegegog.14.03.06
3. Amalia D, Fikriyah A, Tamam B, Sidik RF, Wulandari AYR. The analysis of junior high school students' misconceptions using five-tier diagnostic test in the concept of living things classification. Indones J Math Nat Sci Educ. 2023;4(2):121-134. doi:10.35719/mass.v4i2.133
4. Chi MTH, Wylie R. The ICAP framework: linking cognitive engagement to active learning outcomes. Educ Psychol. 2014;49(4):219-243. doi:10.1080/00461520.2014.965823
5. Dalgarno B, Lee MJW. What are the learning affordances of 3-D virtual environments? Br J Educ Technol. 2010;41(1):10-32. doi:10.1111/j.1467-8535.2009.01038.x
6. Dionisio JDN, Burns WG 3rd, Gilbert R. 3D virtual worlds and the metaverse: current status and future possibilities. ACM Comput Surv. 2013;45(3):Article 34. doi:10.1145/2480741.2480751
7. Girvan C. What is a virtual world? Definition and classification. Educ Technol Res Dev. 2018;66(5):1087-1100. doi:10.1007/s11423-018-9577-y
8. Hwang GJ, Chien SY. Definition, roles, and potential research issues of the metaverse in education: an artificial intelligence perspective. Comput Educ Artif Intell. 2022;3:100082. doi:10.1016/j.caeai.2022.100082
9. Kirschner PA, Sweller J, Clark RE. Why minimal guidance during instruction does not work: an analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching. Educ Psychol. 2006;41(2):75-86. doi:10.1207/s15326985ep4102_1
10. Kolb DA. Experiential learning: experience as the source of learning and development. Englewood Cliffs, NJ: Prentice Hall; 1984.
11. Kye B, Han N, Kim E, Park Y, Jo S. Educational applications of metaverse: possibilities and limitations. J Educ Eval Health Prof. 2021;18:32. doi:10.3352/jeehp.2021.18.32
12. Lin H, Wan S, Gan W, Chen J, Chao HC. Metaverse in education: vision, opportunities, and challenges. arXiv:2211.14951 [preprint]. 2022. Available from: https://arxiv.org/abs/2211.14951
13. Makransky G, Lilleholt L. A structural equation modeling investigation of the emotional value of immersive virtual reality in education. Educ Technol Res Dev. 2018;66(5):1141-1164. doi:10.1007/s11423-018-9581-2
14. Makransky G, Petersen GB. The cognitive affective model of immersive learning (CAMIL): a theoretical research-based model of learning in immersive virtual reality. Educ Psychol Rev. 2021;33:937-958. doi:10.1007/s10648-020-09586-2
15. Makransky G, Terkildsen TS, Mayer RE. Adding immersive virtual reality to a science lab simulation causes more presence but less learning. Learn Instr. 2019;60:225-236. doi:10.1016/j.learninstruc.2017.12.007
16. Makransky G, Lilleholt L, Aaby A. Development and validation of the multimodal presence scale for virtual reality environments: a confirmatory factor analysis and item response theory approach. Comput Human Behav.

2017;72:276-285. doi:10.1016/j.chb.2017.02.066

17. Merchant Z, Goetz ET, Cifuentes L, Keeney-Kennicutt W, Davis TJ. Effectiveness of virtual reality-based instruction on students' learning outcomes in K-12 and higher education: a meta-analysis. Comput Educ. 2014;70:29-40. doi:10.1016/j.compedu.2013.07.033
18. Mystakidis S. Metaverse. Encyclopedia. 2022;2(1):486-497. doi:10.3390/encyclopedia2010031
19. Petersen GB, Petkakis G, Makransky G. A study of how immersion and interactivity drive VR learning. Comput Educ. 2022;179:104429. doi:10.1016/j.compedu.2021.104429
20. Posner GJ, Strike KA, Hewson PW, Gertzog WA. Accommodation of a scientific conception: toward a theory of conceptual change. Sci Educ. 1982;66(2):211-227. doi:10.1002/sce.3730660207
21. Pradana M, Elisa HP. Metaverse in education: a systematic literature review. Cogent Soc Sci. 2023;9(2):2252656. doi:10.1080/23311886.2023.2252656
22. Radianti J, Majchrzak TA, Fromm J, Wohlgenannt I. A systematic review of immersive virtual reality applications for higher education: design elements, lessons learned, and research agenda. Comput Educ. 2020;147:103778. doi:10.1016/j.compedu.2019.103778
23. Schott C, Milligan A, Marshall S. Immersive VR for K-12 experiential education: proposing a pedagogies, practicalities, and perspectives informed framework. Comput Educ X Reality. 2024;4:100068. doi:10.1016/j.cexr.2024.100068
24. Conrad M, Kablitz D, Schumann S. Learning effectiveness of immersive virtual reality in education and training: a systematic review of findings. Comput Educ X Reality. 2024;4:100053. doi:10.1016/j.cexr.2024.100053
25. Sweller J. Cognitive load during problem solving: effects on learning. Cogn Sci. 1988;12(2):257-285. doi:10.1207/s15516709cog1202_4