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Developing a STEAM-Based Water Cycle Diorama Integrating 3D Printing, Virtual Reality, and Local Wisdom: An Educational Design Research

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Abstract. The water cycle is a core topic in elementary IPAS learning, but students often find it difficult because several processes are abstract, dynamic, and not directly observable. This study develops a conceptual design for SIAR Media, a STEAM-based water cycle diorama integrating 3D printing, Virtual Reality (VR), and the local wisdom of the Tongkonan Traditional House. Using Educational Design Research, the study focuses on two initial phases: analysis and exploration, and design and construction. Participants included three elementary school teachers and nine fifth-grade students, while conceptual validation involved subject matter and media experts. Data were collected through semi-structured interviews, literature review, and expert validation, then analyzed thematically and descriptively. Findings show that students recognize basic water cycle stages but still struggle to explain condensation, infiltration, and causal relationships among water cycle components. Teachers also reported that existing media remain limited in connecting concrete objects with invisible scientific processes. The resulting design combines a 3D-printed physical diorama, VR visualization, STEAM-oriented activities, local cultural context, and learning scaffolds. Expert feedback confirms its pedagogical relevance and recommends stronger visualization of process relationships and explicit engineering and mathematics activities.

Keywords: water cycle; STEAM; virtual reality; 3D printing; educational design research; diorama

INTRODUCTION

Science learning in elementary schools should help students understand natural phenomena, use evidence-based reasoning, and relate scientific concepts to daily life. One topic that requires careful instructional design is the water cycle. Although the topic is introduced in elementary IPAS learning, it involves interconnected processes such as evaporation, condensation, precipitation, infiltration, transpiration, surface runoff, and water collection. These processes occur continuously and many of them cannot be directly observed during classroom activities. Consequently, students often memorize the sequence of events without fully understanding the causal relationships among the atmosphere, Earth's surface, living organisms, soil, and groundwater. Prior studies report that elementary students frequently view the water cycle as a simple linear process of evaporation, cloud formation, and rainfall, while the systemic role of infiltration, groundwater, and human-environment interactions is less understood (Barrutia et al., 2021; Baumfalk et al., 2019; Hulings et al., 2026).

Instructional media used in schools can either reduce or intensify this difficulty. Textbooks, two-dimensional pictures, diagrams, videos, and verbal explanations are useful for introducing terminology, but they tend to provide static or one-way representations. Simple dioramas offer concrete visual support, yet they cannot fully show dynamic changes such as water vapor rising, clouds forming, rain falling, and water entering the soil. This gap between concrete classroom media and invisible scientific processes indicates the need for a more integrated representation. Physical media are still needed because elementary students benefit from tangible objects and spatial orientation. At the same time, virtual media are needed to make unobservable processes visible and explorable.

Recent research suggests that dioramas can support elementary students' understanding of the water cycle by presenting environmental components in a concrete three-dimensional form (Humaira & Ninawati, 2023; Yosua Marasi Parningotan Siagian et al., 2025). VR can further enrich science learning by allowing students to observe processes that are difficult to access directly, including evaporation, condensation, precipitation, and infiltration (Bogusevschi & Muntean, 2019; Martarelli et al., 2025; Ummah et al., 2025). However, technology should not be added only as a visual attraction. It needs a pedagogical framework that connects scientific concepts, technology use, engineering design, aesthetic and cultural meaning, and mathematical reasoning. The STEAM approach is suitable for this purpose because it emphasizes interdisciplinary problem solving and is product-oriented (Adriyawati et al., 2020; Halimah et al., 2025; Winarni et al., 2024).

Based on these considerations, this study proposes SIAR Media, a STEAM-based water cycle diorama that integrates 3D printing, VR, and local wisdom from the Tongkonan Traditional House. The novelty of the study lies in the conceptual integration of physical and virtual representations within a contextual STEAM design. The study does not yet test learning effectiveness; rather, it formulates a design rationale and initial design principles for prototype development. The objectives are to analyze teacher and student needs in water cycle learning, formulate a conceptual design for SIAR Media, and validate the design through expert feedback.

METHODS

This study employed Educational Design Research (EDR) because the aim was to develop a learning solution grounded in real classroom needs and theoretical considerations. The study focused on the first two phases of EDR: analysis and exploration, and design and construction. The analysis and exploration phase identified students' conceptual barriers, teachers' instructional challenges, and limitations of existing learning media. The design and construction phase translated these findings into a conceptual media design integrating a physical diorama, VR visualization, 3D printing, STEAM learning components, and local cultural context.

The participants consisted of three elementary school teachers who had experience teaching the water cycle and nine purposively selected fifth-grade students. Teachers provided information about classroom practices, media use, student difficulties, and the need for more suitable instructional media. Students provided information about their prior understanding of the water cycle, concepts they found difficult, and media characteristics they expected. In addition, a science subject matter expert and an instructional media expert validated the conceptual design.

Data were collected using semi-structured interviews, literature review, and expert validation. Teacher interviews focused on the learning process, media commonly used, student misconceptions, and media needs. Student interviews explored understanding of water cycle stages, difficulty in explaining invisible processes, and preferences for concrete and interactive learning experiences. The literature review examined studies on water cycle misconceptions, diorama-based learning, VR in science education, 3D printing, STEAM learning, multimedia learning, science literacy, numeracy literacy, and EDR. The expert validation instrument examined conceptual accuracy, visualization quality, STEAM integration, cultural relevance, suitability for elementary learners, and recommendations for revision.

Interview data were analyzed thematically through repeated reading, initial coding, theme grouping, and interpretation. Expert validation data were analyzed descriptively to identify strengths, weaknesses, and revision priorities. Source triangulation was applied by comparing teacher responses, student responses, literature findings, and validator feedback. The final output of this stage was a validated conceptual design and a set of initial design principles for the next prototype development phase.

RESULTS AND DISCUSSION

Students' cognitive barriers and instructional media limitations

The interviews indicate that fifth-grade students generally recognize basic water cycle terms, especially evaporation, clouds, and rain. However, their understanding remains partial. Students tend to describe the water cycle as a linear sequence rather than as a dynamic system. The most difficult concepts are condensation, infiltration, subsurface water movement, and the causal relationships among water cycle components. Teachers reported that students often need to imagine processes that cannot be seen directly, which may lead to confusion or misconceptions. This finding is consistent with studies showing that elementary students need representational and modeling support to understand hydrological systems as interconnected processes rather than isolated events (Baumfalk et al., 2019; Levy & Moore Mensah, 2020)

Teachers also reported that existing instructional media are helpful but insufficient. Textbooks and pictures introduce vocabulary and stages, but they do not show movement or change. Videos provide motion, yet students mostly watch passively. Simple dioramas make components such as mountains, clouds, rivers, land, plants, and settlements more concrete, but they cannot demonstrate invisible processes such as vapor movement, cloud formation, infiltration, and groundwater flow. Therefore, the main instructional need is media that can link concrete environmental objects with dynamic scientific processes.

This need supports the integration of physical and virtual representations. A physical diorama can function as a spatial anchor that helps students identify components and their positions in the water cycle system. VR can then display dynamic and invisible processes that are difficult to present through physical media. This combination aligns with multimedia learning principles, which emphasize the use of complementary verbal, visual, and spatial representations to support coherent mental model construction (Delgado & Mayer, 2025; Makransky & Petersen, 2021). However, multiple representations must be carefully sequenced so that they reduce, rather than increase, students' cognitive load.

Taken together, the needs analysis indicates that the main learning problem is representational rather than merely motivational. Students do not simply need additional attractive media; they need coordinated representations that help them move from naming the stages of the water cycle to explaining how the stages are connected. For this reason, the design requirement was formulated as the integration of three forms of support: a concrete spatial model, a dynamic visualization of invisible processes, and guided learning activities that require students to observe, compare, explain, measure, and reflect.

This result also clarifies the role of teachers in the planned implementation. Teachers require media that can reduce lengthy verbal explanation and provide shared objects for classroom discussion. The diorama is expected to become the common reference point during observation, while VR is used when students need to examine processes that cannot be shown through the diorama alone. Therefore, the media must be accompanied by prompts and worksheets so that students do not passively watch or play with the media, but actively construct explanations based on evidence from both representations.

Conceptual design of SIAR Media

The conceptual design of SIAR Media was formulated as a learning package consisting of four core elements: a 3D-printed water cycle diorama, VR-based visualization of water cycle processes, STEAM-oriented learning activities, and scaffolding tools such as student worksheets and teacher guidance. The physical diorama represents concrete environmental components, including mountains, clouds, sun, rivers, seas, soil layers, vegetation, settlements, and the Tongkonan Traditional House. The VR component visualizes processes such as evaporation, condensation, precipitation, infiltration, surface runoff, and water collection. By moving between the diorama and VR, students are expected to connect visible structures with invisible processes.

The STEAM framework gives each media component a clear instructional function. The Science component is represented by water cycle concepts and explanations of state changes, weather processes, and water movement. The Technology component appears in the use of VR and 3D printing. The Engineering component is reflected in designing, constructing, testing, and revising diorama components. The Arts component appears in the visual design of the diorama and the integration of local cultural elements, particularly the Tongkonan Traditional House. The Mathematics component is expressed through scale, proportion, measurement, geometry, comparison, rainfall data reading, and simple graph interpretation. Thus, STEAM in this study is not used only as a label, but as a design framework that organizes learning activities. The framework is displayed in Figure 1.

Figure 2 emphasizes that the five STEAM components are interconnected in one learning design. Science provides the conceptual focus, namely water movement and changes in state. Technology is represented by VR and 3D printing, but its function is pedagogical rather than merely technical. Engineering appears when students analyze the problem, arrange components, test whether the representation is logical, and revise the product. Arts is expressed through visual composition and the Tongkonan cultural context, while Mathematics is integrated through measurement, scale, proportion, geometry, and data interpretation. This structure prevents STEAM from becoming a superficial label and ensures that each component contributes to a specific learning activity.

The use of 3D printing strengthens the engineering dimension because it allows the production of precise, modifiable, and reusable components. In later classroom implementation, students can be introduced to design thinking through activities such as selecting component shapes, considering scale, arranging environmental elements, testing whether water movement is represented logically, and revising the product. The inclusion of the Tongkonan Traditional House provides cultural contextualization. It helps students connect science learning with familiar local environments and shows that scientific phenomena occur within social and cultural spaces. This contextual element also strengthens the Arts dimension of STEAM by combining aesthetics, cultural meaning, and scientific representation. The conceptual design process is presented in Figure 2, while the relationship between needs, design decisions, and rationales is summarized in Table 1.

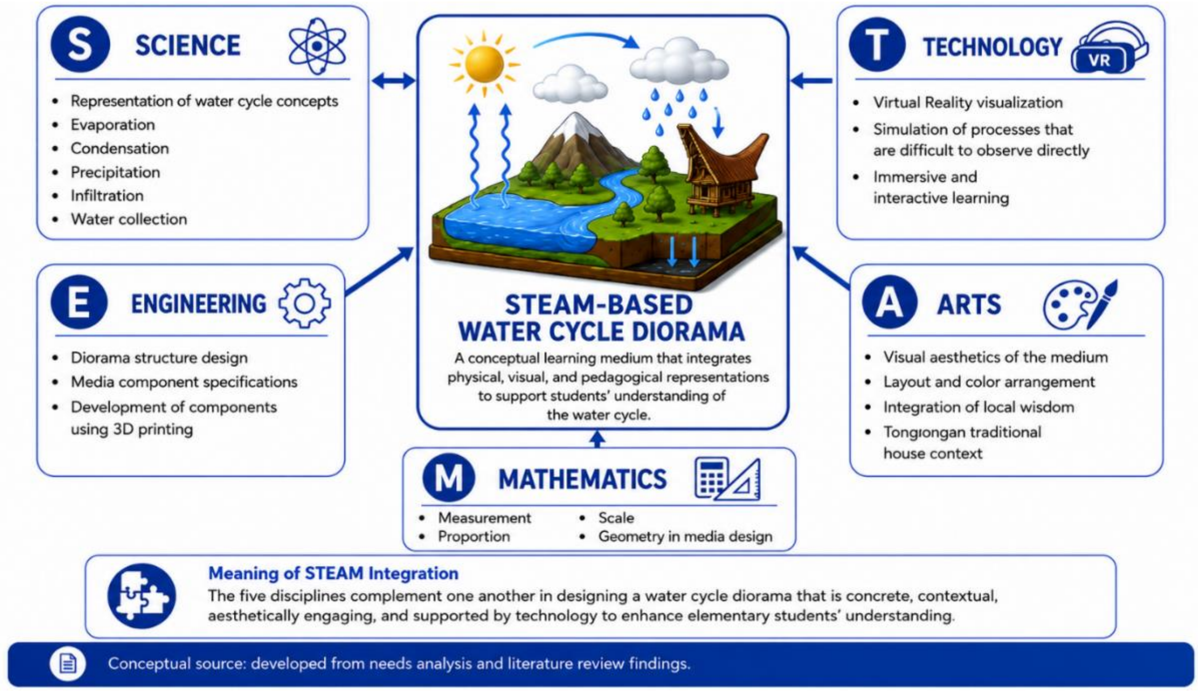

Figure 1. STEAM integration framework in the development of a water cycle diorama.

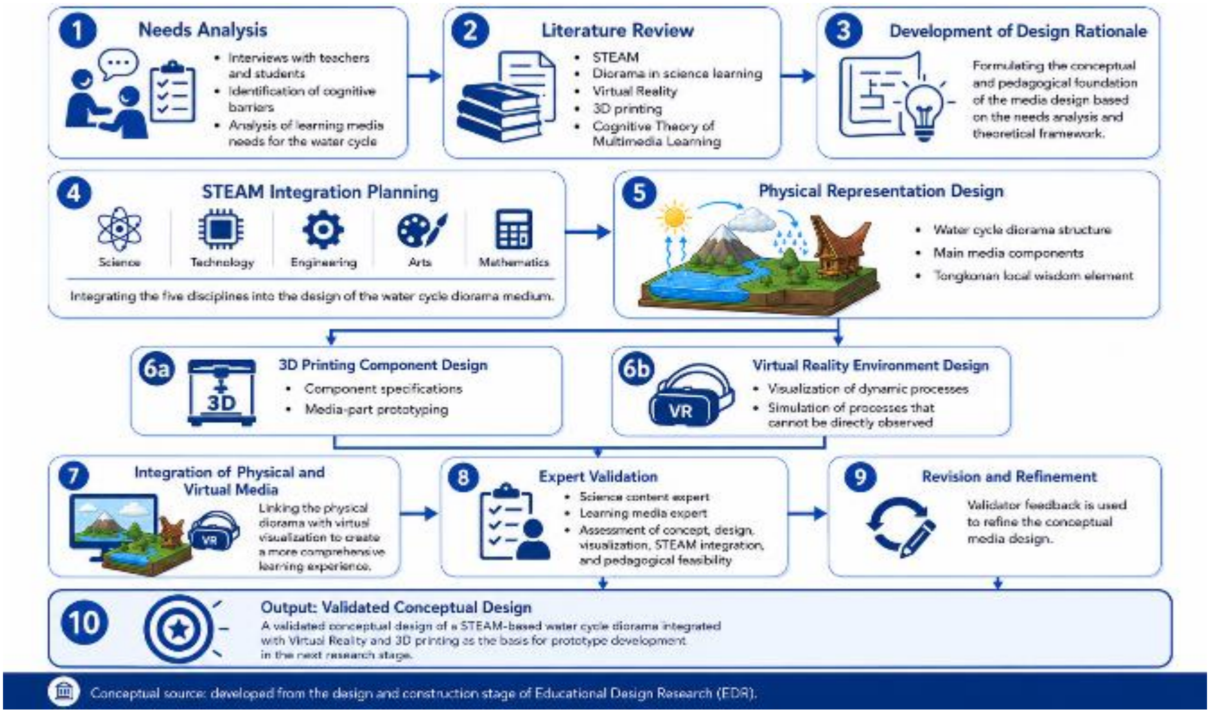

Figure 2. Conceptual design process of SIAR Media.

Table 1. Relationship between needs, design decisions, and theoretical rationales

Needs	Design decision	Rationale
Abstract processes are difficult to visualize.	Use VR for dynamic water-cycle processes.	VR makes invisible phenomena observable.
Students need concrete representations.	Build a 3D water-cycle diorama.	Diorama clarifies spatial relations.
Teacher media remain static.	Integrate physical and virtual media.	Combined representations support mental models.
Design activity is still limited.	Use 3D printing for diorama components.	3D printing strengthens engineering and prototyping.
Science is weakly linked to local culture.	Use Tongkonan cultural context.	Local context increases relevance and meaning.
Numeracy is not explicit.	Add scale, measurement, geometry, and data tasks.	These tasks strengthen numeracy in IPAS learning.

Figure 2 and Table 1 show how the conceptual design was derived from empirical and theoretical considerations. The development did not begin with technology selection alone, but with the identification of students' cognitive barriers and teachers' media needs. These findings were compared with literature on water cycle misconceptions, multimedia learning, immersive visualization, concrete models, STEAM learning, and EDR. The synthesis was then translated into design decisions: using VR for dynamic processes, using a 3D diorama for spatial representation, using 3D printing for engineering and prototyping, using Tongkonan local wisdom for contextualization, and adding mathematical activities to strengthen numeracy.

The table also functions as a design control mechanism. Each media feature must be justified by a learning need and a theoretical rationale. For example, VR is included because evaporation, condensation, and infiltration are difficult to observe directly; 3D printing is included because the design requires precise and modifiable components; and the Tongkonan element is included because local context can increase relevance and meaning. This mapping is important for maintaining coherence between problem, design decision, and expected learning support.

Expert validation and design revision priorities

Expert validation showed that the conceptual design is relevant for elementary IPAS learning because it addresses the abstract and dynamic nature of the water cycle. Subject matter experts considered the selected concepts appropriate for fifth-grade learning, particularly evaporation, condensation, precipitation, infiltration, surface runoff, and water collection. However, they recommended that the relationships among processes be visualized more explicitly so that students do not interpret the water cycle as separate steps. The revised design should therefore show how solar heat drives evaporation, how water vapor becomes clouds, how precipitation returns water to the surface, and how infiltration and runoff reconnect water with rivers, soil, and groundwater.

Media experts appreciated the innovative integration of physical dioramas, VR, and 3D printing, but emphasized that the media must be supported by clear learning scenarios. Students should know when to observe the diorama, when to explore VR, what questions to answer, what measurements to make, and how to reflect on the connection between both representations. Without scaffolding, students may treat VR as entertainment and the diorama as decoration. Therefore, the next prototype should include student worksheets, teacher guidance, observation prompts, measurement tasks, discussion questions, and reflection activities.

Validators also recommended strengthening the engineering and mathematics components. Engineering should be visible through design, construction, testing, and revision activities. Mathematics should be visible through scale, proportion, measurement, comparison, data recording, and simple interpretation of rainfall or water volume data. These revisions are important because SIAR Media is intended not only to improve conceptual understanding but also to support science literacy and numeracy literacy.

The validation stage therefore produced formative evidence for refinement. The experts did not reject the design, but they indicated that the next prototype must make the learning sequence clearer. A possible sequence is: initial observation of the diorama, prediction of water movement, VR exploration of invisible processes, group discussion, measurement and data tasks, redesign or refinement of the diorama model, and reflection on the water cycle as a system. Such sequencing is expected to help students connect concrete, virtual, verbal, and numerical information without experiencing unnecessary cognitive load.

Initial design principles

The synthesis of needs analysis, literature review, and expert validation produced seven initial design principles. First, abstract science concepts in elementary learning should begin with concrete representation. Students need a physical and spatial foundation before they are asked to explain processes that cannot be seen directly. Second, immersive visualization should be used to show dynamic processes such as evaporation, condensation, precipitation, infiltration, and runoff. Third, physical and virtual media should be designed as complementary representations, not as separate learning tools. The diorama helps students recognize environmental structures, while VR helps them understand the mechanisms occurring within those structures.

Fourth, the engineering element should be realized through design activity. Students should not only view a finished product but also engage with the process of designing, constructing, testing, and improving components. Fifth, mathematics should be made explicit through measurement, scale, proportion, geometry, comparison, data recording, and graph interpretation. Sixth, local culture should be integrated to increase relevance and meaning. In this design, the Tongkonan Traditional House functions as a contextual element that connects science with students' social and cultural environment. Seventh, complex media should be supported by scaffolding. Worksheets, guiding questions, teacher instructions, VR exploration tasks, group discussion, and reflection are needed to ensure that the technology supports learning objectives. The seven principles are summarized in Figure 3.

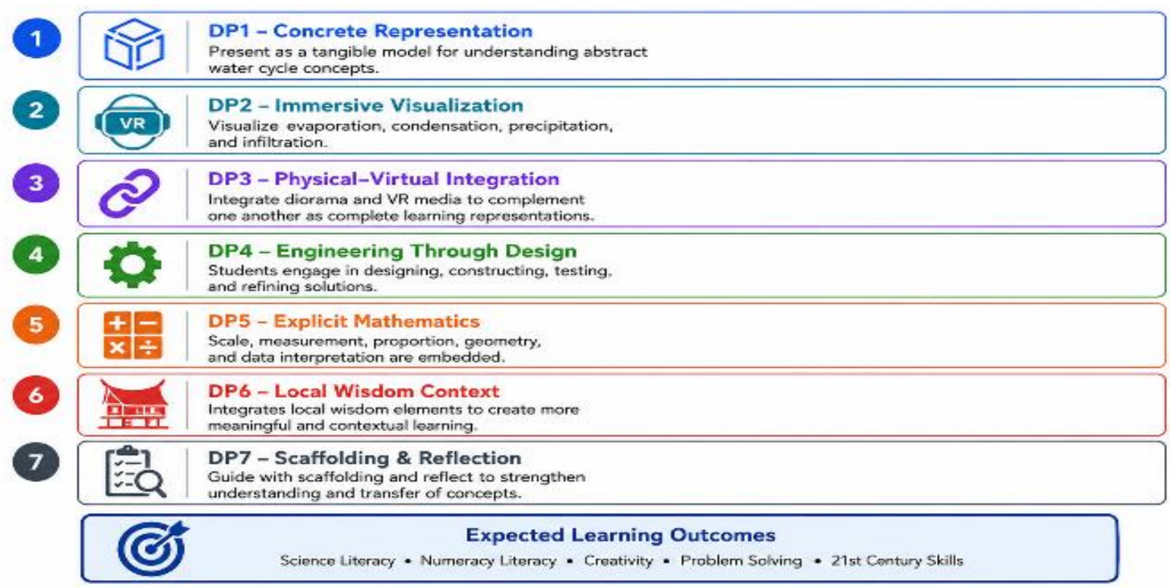

Figure 3. Design principles of SIAR Media

These principles provide the conceptual basis for the next stage of SIAR Media development. The prototype should be developed as an integrated learning package consisting of a 3D-printed diorama, VR visualization, STEAM-based student worksheets, a teacher guide, and assessment instruments for science literacy and numeracy literacy. Future implementation should test whether the integrated media improves students' conceptual understanding, science literacy, numeracy literacy, engagement, and ability to explain the water cycle as a system.

The implication of these findings is that SIAR Media should be developed as a complete instructional system rather than as a single visual aid. The media package should include a physical prototype, VR scenes, student worksheets, teacher instructions, assessment rubrics, and instruments for science literacy and numeracy literacy. The worksheets should guide students to identify components, explain processes, measure model dimensions, compare proportions, read simple rainfall or water-volume data, and communicate conclusions. In this way, the media can support conceptual understanding while also encouraging inquiry, collaboration, creativity, and evidence-based reasoning.

For future testing, the prototype should be evaluated in stages. A limited trial is needed to examine readability, usability, students' navigation of VR, clarity of worksheets, and the practicality of classroom management. Field testing can then examine learning outcomes more systematically, including improvement in water cycle understanding, science literacy, numeracy literacy, engagement, and students' ability to explain causal relationships. This staged evaluation is consistent with the EDR orientation, in which design products and design principles are refined through iterative cycles of implementation, reflection, and revision.

CONCLUSION

This study developed a conceptual design for a STEAM-based water cycle diorama integrating 3D printing, VR, and local wisdom from the Tongkonan Traditional House. The analysis showed that fifth-grade students recognize basic water cycle stages but still struggle to explain invisible and interconnected processes, especially condensation, infiltration, groundwater movement, and causal relationships among components. Teachers need media that can connect concrete objects with dynamic scientific visualization.

The proposed design responds to this need by combining a physical diorama as a concrete spatial representation, VR as an immersive visualization tool, 3D printing as an engineering and prototyping support, STEAM as an interdisciplinary framework, and local culture as a contextual anchor. Expert validation indicates that the design is pedagogically relevant but should be refined by clarifying relationships among processes, strengthening the integration of physical and virtual media, and making engineering and mathematics activities more explicit. The main contribution of this study is the formulation of design rationale and seven initial design principles for SIAR Media. This study remains limited to conceptual design and initial validation; therefore, future research should develop a functional prototype, conduct limited and field trials, and evaluate effectiveness through experimental or quasi-experimental designs.

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