DIJEMSS: Dinasti International Journal of Education Management and Social Science
E-ISSN: 2686-6331
P-ISSN: 2686-6358
https://dinastipub.org/DIJEMSS dinasti.info@gmail.com +62 811 7404 455
DINASTI PUBLISHER
DOI: https://doi.org/10.38035/dijemss.v7i1
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Virtual Reality-Based Learning Media for Enhancing Computational Thinking in Junior High Schools

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Abstract: This study developed and evaluated Bytethink7, a Virtual Reality (VR)-based learning medium to improve Computational Thinking (CT) skills among seventh-grade students at SMP Negeri 3 Jatipuro, Indonesia. The application was designed using the 4D model (Define, Design, Develop, Disseminate) and developed with Unity3D, SketchUp, Blender, Vroid, and Adobe Photoshop. Validation by two media experts and two subject matter experts yielded highly satisfactory results, with a Likert score of 86.25%, Aiken's V of 0.825 (very high content validity), and all content criteria met according to the Guttman scale (100%). Black-box functionality testing showed the application runs perfectly (100%), while testing with 22 students yielded an average System Usability Scale (SUS) score of 74, categorized as "Good or Acceptable." These findings indicate that Bytethink7 is effective as an interactive learning medium that supports the constructivist learning-by-doing principle and can serve as a solution to the lack of CT learning tools at the junior high school level. Further research is recommended to test its impact on CT skill attainment and compare it with other educational technologies.

Keyword: Computational Thinking, Junior High School, Learning Media, Virtual Reality.

INTRODUCTION

Computational Thinking (CT) has emerged as a critical skill in the 21st-century education landscape, underpinning students' ability to solve problems and think algorithmically in various domains (Angeli & Giannakos, 2020). Wing in Varela et al. (2019) famously described CT as an approach to problem-solving that can "influence every human endeavour," positioning it as an essential competency for modern learners. Computational thinking in professional human resources can be improved through internal and external collaboration (Bunahri, 2023). Many national curricula, including Indonesia's Kurikulum Merdeka, now integrate CT concepts into subjects like mathematics and informatics at the junior high school level. However, despite this curricular emphasis, educators face challenges in delivering CT content in engaging and accessible ways (Lemay et al., 2021). Traditional teaching methods such as lectures, textbooks, or basic computer demos may fail to provide the hands-on experience and interactive problem-solving that CT education demands (Achmad et al., 2025).

The shift in learning styles from verbal or visual to virtual promotes the use of AR-based learning materials (Sari et al., 2022). VR differs from other learning media, and high immersion in VR environments can create a sense of presence, which improves learning outcomes (Sari et al., 2021). There is a clear need for innovative learning media that can actively involve students in CT practices, yet schools often lack such interactive tools for CT learning at the junior high level (Suarsana et al., 2024). Rapid growth and complexity globally require the application of computational thinking to decipher patterns, formulate data-driven solutions, and design adaptive systems in response to the dynamic changes in the world (Bunahri et al., 2023).

Virtual Reality (VR) technology offers a promising solution by creating immersive learning environments where abstract computational concepts can be experienced concretely. Prior research suggests that immersive VR applications provide presence, interactivity, and immediate feedback, which can enhance student engagement and motivation (Bunahri, 2025). For example, Cheng et al. (2023) found that an educational VR game improved learners' creative thinking and systematic reasoning key elements of CT by situating them in a 3D problem-solving world. VR's characteristics of immersion and interaction enable learners to visualize and manipulate complex problems, thereby aligning with the way CT encourages understanding through doing. Indeed, VR applications have also been shown to offer cognitive benefits, such as improved reasoning and reflective thinking, by engaging learners with virtual objects and environments. Despite these advantages, a recent systematic review by Suri et al. (2023) revealed that only about 12% of VR-based educational games explicitly target problem-solving skills. This indicates that the potential of VR for teaching CT skills remains underexplored and underutilized, especially in secondary education contexts.

Several previous studies and developments highlight both the potential and the gap that the present work aims to fill. Endarto & Martadi (2022) developed a digital book ("digibook") using the Anyflip platform to teach mathematical sequences and series as a means to foster CT skills, demonstrating the effectiveness of interactive e-books in improving students' computational thinking. However, that approach was 2D and lacked the immersion that VR can provide. Similarly, Arfiansyah et al. (2023) created an educational game titled "Visiting Grandma's House" to integrate CT into elementary-level thematic learning, showing that gamified story-based learning can engage young students with CT concepts. Yet, that work was situated in an elementary context and did not utilize immersive VR. In another related study, Ung et al. (2022) implemented a VR-based learning media for computer hardware assembly training, indicating the viability of VR for technical education in Indonesian high schools. Musril et al.'s project, while not focused on CT per se, confirmed that VR media could effectively deliver complex procedural content (assembling computer components) in a vocational setting. These prior works collectively suggest that interactive and multimedia approaches (e-books, games, and VR) can improve engagement and skill acquisition in computational domains; however, none specifically addressed the integration of VR technology with CT curricula for junior high school students (Suarsana et al., 2024). Bytethink7 distinguishes itself by directly targeting the CT curriculum for Grade 7 with a fully immersive VR approach, providing students with a first-person, experiential learning environment for CT. This focus on CT content in VR for junior high is a novel contribution, building upon Sukirman et al. (2022) call for more game-based VR (GBiVR) strategies to enhance CT learning.

Given this background, the current study was undertaken to develop and evaluate Bytethink7, a VR-based learning media aimed at improving the CT abilities of seventh graders. The primary research questions were: (1) How can a VR learning media be designed and developed to align with the Grade 7 CT curriculum and pedagogical needs? (2) Is the resulting VR application educationally valid and usable according to experts and students? and (3) How do students perceive the usability and learning experience provided by the VR environment? To answer these questions, we adopted a Research and Development approach using the 4D instructional design model, and conducted expert validations and student usability testing.

Theoretically, our work is grounded in constructivism, the idea that learners construct knowledge best through active, contextual experiences and in immersive learning theory, which suggests that technologies like VR can create rich experiential learning environments (Makransky & Petersen, 2021). We also consider cognitive load implications and the Technological Pedagogical Content Knowledge (TPACK) framework, to ensure that the technology integration is pedagogically sound. By combining these perspectives, we aimed to create a VR learning tool that is not only novel, but also effective and aligned with educational best practices. The following sections detail the development process of Bytethink7, the evaluation methods, results obtained, and discussions on how this VR tool fits into the broader context of educational technology for computational thinking.

METHOD

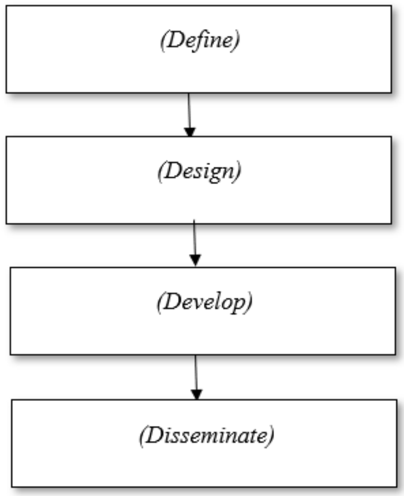


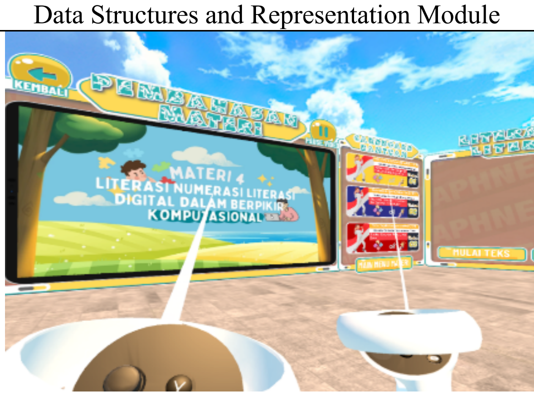
Figure 1. 4D Model

This study uses the Design and Development approach with the 4D model (Define, Design, Develop, Disseminate) from Thiagarajan to develop the Bytethink7 VR learning media. The Define stage involved analyzing the needs and curriculum of Grade VII Informatics, which identified a lack of interactive media in CT learning. In the Design stage, a VR concept was developed in the form of a virtual classroom and laboratory with CT-based activities, using Unity3D, SketchUp, Blender, and Vroid Studio. Next, the Develop stage included the implementation of the design through gaze-based interaction programming, performance optimization on smartphones, and formative testing for user comfort and bug fixes. Finally, the Disseminate phase was conducted through functional testing by three students, field testing in two seventh-grade classes at SMPN 3 Jatipuro, and the provision of application usage guidelines for teachers and students. This process ensures that Bytethink7 is suitable for use as an effective VR-based learning medium aligned with the curriculum.

The evaluation of Bytethink7 involved three groups: expert validators (two media experts and two computer science teachers from SMP Negeri 3 Jatipuro), 22 seventh-grade students (aged 12–13 years) as primary users, and three students from different classes for technical testing (black-box). The students already had basic CT knowledge but had never learned to use VR. Data collection was conducted quantitatively and qualitatively using instruments including: (1) expert validation questionnaires based on the Likert scale and Guttman scale to assess content suitability, learning design, media quality, and student engagement, (2) the System Usability Scale (SUS) completed by students after using VR to measure system usability, (3) a student feedback questionnaire regarding perceptions of learning and interest in CT, and (4) observations and activity logs of students while using the application. This data provides a comprehensive overview of the validity, usability, and potential educational impact of Bytethink7 in the context of VR-based learning.

RESULTS AND DISCUSSION

Table 1. Conceptual Framework and Content Analysis of Computational Thinking for 7th Grade Junior High School within the Bytethink7 VR Application

Learning Content	VR Application Visual
Basic Techniques of Computational Thinking	 Basic Computational Thinking Techniques
Algorithms in Computational Thinking	 Computational Thinking Algorithm Module
Data Structures and Data Representation	 Data Structures and Representation Module
Numerical and Digital Literacy in Computational Thinking	 Numerical and Digital Literacy Module

The Bytethink 7 Virtual Reality (VR) application is designed to deliver a structured and immersive learning experience for junior high school students by integrating key concepts of computational thinking into a digital environment. The core learning modules embedded in the application include four essential topics: basic computational thinking techniques, algorithmic logic, data structures and representations, and the integration of numeracy and digital literacy. Each module is visually represented within the VR application to enhance students' cognitive engagement and understanding. For instance, Figure 2 presents the foundational concepts of decomposition, pattern recognition, abstraction, and algorithm design, which are contextualized in real-life problem scenarios. Figure 3 illustrates algorithmic thinking through interactive simulations where students sequence logical steps to solve tasks. Figure 4 introduces visual metaphors for understanding data structures and how data is represented and manipulated in computing contexts. Lastly, Figure 5 bridges computational thinking with essential 21st-century skills, such as digital and numerical literacy, enabling students to make informed decisions in digital environments. This content alignment not only supports the national curriculum goals but also aligns with constructivist learning theories by enabling learners to interact with abstract concepts through experiential and exploratory modes within the VR ecosystem.

Expert Validation Results

The evaluations by the expert panel indicated a strong approval of Bytethink7's content and design. Table 3 presents a summary of the expert validation scores. The two media experts and two content experts' Likert-scale ratings were aggregated, yielding an overall content feasibility score of 86.25%. According to the predefined criteria, this percentage falls in the "Sangat Layak" category (translated as "Very Eligible/Very Feasible") for use in instruction. In practical terms, experts judged that the VR learning media is very much suitable for supporting the teaching-learning process. Breaking down by aspect, content accuracy and alignment with curriculum were highly rated (average ~4.3 out of 5 points), and instructional design (clarity of objectives, sequence of activities) also received favorable ratings (~4.2/5). Media/technical quality (user interface, graphics, audio) had slightly varied scores but remained high (~4.0–4.5/5); one media expert commented that "the visual design is impressive for a school-level project, although the text readability in VR could be further improved".

Aiken's V calculation for content validity, based on the content experts' item ratings, resulted in V = 0.825. This value is well above common acceptability thresholds (for 4 experts, a V > 0.78 is typically considered significant at $p < .05$) and thus indicates very high content validity. In other words, the subject-matter experts strongly agreed that Bytethink7 covers the necessary CT content correctly and appropriately for Grade 7. All critical content elements (definitions of CT concepts, examples given, difficulty level of problems) were marked as valid by both content experts, yielding a Guttman scale score of 100% (all "Yes" to validity checklist). This unanimous agreement confirms that there were no content flaws or omissions identified. An example item from the content checklist was "The examples used in the VR (e.g., a daily life algorithm scenario) are relevant and help illustrate the CT concept" – both experts marked "Yes" for such items consistently.

Table 2. Expert Validation Summary for Bytethink7

Evaluation Aspect	Indicator (example items)	Score / Agreement	Interpretation
Content Quality (Subject-Matter)	Alignment with curriculum; Accuracy of CT concepts; Appropriateness for Grade 7.	Likert score 86.25% (Mean ~4.3/5); Aiken's V = 0.825; Guttman "Yes" = 100%.	**Very High Validity** – content is accurate, relevant, and complete for CT Grade 7.
Instructional Design	Clarity of learning objectives; Sequence and	Likert score ~84% (Mean ~4.2/5).	**Very Eligible** – pedagogical design is

Evaluation Aspect	Indicator (example items)	Score / Agreement	Interpretation
	flow of activities; Constructivist alignment (active learning).		sound and supports learning objectives.
Media Design & Usability	Interface clarity; Visual and audio quality; Ease of navigation in VR.	Likert score ~80% (Mean ~4.0/5).	**Eligible/Good** – overall interface is user-friendly; minor suggestions given (e.g., enlarge text).
Engagement/Motivation Potential	Student engagement; Motivation to learn (as perceived by experts).	Likert score ~88% (Mean ~4.4/5).	**Very Eligible** – VR media is judged to be highly engaging and motivating for students.
Overall	Combined content and media evaluation.	**86.25% overall score**.	**(Very Feasible)** – the media is deemed very suitable for classroom use.

Note: Scores are averaged across four experts. "Likert score" represents percentage of maximum points; categories per Indonesian criteria: ≥80% = Sangat Layak (Very Eligible), 60–79% = Layak (Eligible), etc. Aiken's V range 0 to 1 (≥0.8 considered high). Guttman scale agreement >50% indicates validity.

In addition to numeric scores, experts provided qualitative feedback. Content experts appreciated that Bytethink7 "covers all the basics of computational thinking in a way students can relate to". They noted the inclusion of Indonesian language in instructions and examples, which helped contextually (the app's text and audio were in Bahasa Indonesia, making it accessible to the target users). One suggestion was to expand content for future versions: e.g., "include more real-world examples of algorithms, perhaps a simple cooking recipe algorithm in VR" to strengthen the connection between CT and everyday life. Media experts, on their part, praised the application's immersive aspect: "The VR environment is highly immersive; students will love the virtual lab experience". They did, however, caution about usability for first-time VR users – recommending a short tutorial (which we had, but they advised making it skippable once the student is familiar). There was also a suggestion to implement an option for teachers to switch the language to English if used in bilingual programs, potentially increasing its versatility (this was beyond our current scope, but noted as a valuable idea). Overall, the expert consensus was that Bytethink7 is a valid and effective learning media, with all experts recommending its use in the classroom after minor refinements. This addresses our first research question, indicating the product meets expert standards for content and design quality.

Student Usability and Feedback

The primary metric for student evaluation was the System Usability Scale (SUS). The average SUS score from the 22 student respondents was 74.0 (on the 0–100 scale). According to SUS benchmarks, this score falls at the threshold of "Good" usability and corresponds to a Grade B (Acceptable) rating. In the acceptability range, it is in the "Acceptable" zone (scores above 68 are generally considered acceptable, and 74 is comfortably above this). Figure 2 (embedded in the text) shows the distribution of SUS scores and their adjective ratings for each student – it indicates that the majority of scores cluster in the 70–80 range, with a few higher (one student gave a score equivalent to 85, and a couple gave around 65, which is still on the borderline of acceptable). No student rated the system below 60, which suggests that even the lowest experience was around "OK" in adjective terms. The SUS results imply that, from the students' perspective, Bytethink7 is easy to use and learn, even as their first VR encounter.

Delving into specific SUS items, the statements that received the most favorable responses (high agreement) were: "I found the system easy to use," and "I felt very confident using the system." These positive responses indicate that the controls and interface metaphors (gaze pointing, selection, etc.) were intuitively understood by this young audience. Statements that were slightly less agreed upon (though not strongly disagreed either) included: "I thought the system was easy to learn" (a few students rated this neutral, possibly reflecting an initial learning curve with VR) and "I think I would need the support of a technical person to use this system" (some were unsure, as they did have assistance during the trial – this suggests that truly independent use might require a brief training or repeated exposure). The item "There were too many inconsistencies in the system" was overwhelmingly marked as Strongly Disagree, meaning students found the system consistent in operation.

To provide a concrete interpretation: A SUS of 74 places Bytethink7 around the 70th–75th percentile of all kinds of systems in terms of usability, based on prior research (Bangor et al., 2009). It is comparable to, for example, how users rate typical mobile apps or educational software in general – indicating that despite being VR (which can be tricky for novices), the usability is on par with conventional tools after initial familiarization. This is a promising result, as one concern was whether 12-year-olds would manage VR controls; the data suggests they can, given appropriate design and minor guidance. Beyond SUS, the student feedback questionnaire showed that 90% of the students responded "Agree" or "Strongly Agree" to the statement "I enjoyed learning with Bytethink7." Many described the experience as "fun" and "exciting" in their open-ended comments. One student wrote, "Belajar pakai VR serasa main game, jadi nggak bosan" (translation: "Learning using VR feels like playing a game, so it's not boring"), highlighting the motivational aspect. In terms of perceived learning: about 82% agreed that they learned something new or understood CT better through the VR activities. We did not administer a formal pre-test/post-test of CT knowledge in this pilot, but this self-report is encouraging as an initial indicator of learning effectiveness. A few students (around 3 out of 22) were neutral on whether they learned more via VR, possibly implying they felt they already knew the basics or that it was more a practice tool than new information – which aligns with the use of Bytethink7 as a reinforcement tool for concepts introduced in class.

Observation notes during the sessions support these findings: students were observed to be highly engaged – many verbally celebrated when they solved a puzzle or found an Easter egg we hid in the environment (we included a small "secret" like a virtual pet that appears, to increase exploratory behavior). Some students naturally started to collaborate, e.g., one would give hints to another if stuck on a puzzle, even though each had their own headset. This social interaction around the VR content is an added benefit, showing that the technology did not isolate them completely from peer learning. No significant usability problems were observed. There were a few minor issues: two students initially wore the headset incorrectly (tilted, causing a blurry view) until we adjusted it for them – this suggests that including a brief instruction on properly wearing the VR headset is important. Also, one student reported slight dizziness after about 15 minutes; he took a short break and then was fine – we attribute this to typical VR adaptation, and fortunately the effect was mild and not widespread. We ensured good ventilation and allowed students to be seated or stand as they preferred, to maximize comfort.

Technical Testing (Black-box results): The black-box test conducted by 3 users (not part of the 22) yielded a 100% success rate on a checklist of functionality. This means all features (loading scenes, interactive objects, audio playback, logging of actions, etc.) performed as intended with no crashes or major bugs encountered. This quantitative result is straightforward, but noteworthy because it indicates the VR application was stable even on the mid-range smartphones used. Start-up time was about 10 seconds, which was acceptable. Memory usage was within limits, and no device overheated during the ~20 minute usage, which was a concern in planning. These technical confirmations gave confidence in proceeding with the educational evaluation without interruptions. In summary, the results can be encapsulated as follows: (1) Expert validators rated Bytethink7 as very high in validity and feasibility for classroom use, with objective measures (Likert percentage, Aiken's V, Guttman agreement) all in the top categories. (2) Student users found Bytethink7 to have good usability (SUS Grade B) and reported positive learning experiences, with strong engagement and no major difficulties in using the VR system. (3) All intended functions of the VR media operated correctly, and both experts' and students' feedback pointed to only minor improvements needed (such as UI tweaks and additional content in the future).

These findings address our research questions by demonstrating that a VR learning media for CT can be developed that meets expert quality criteria and is usable by the target learners. In the next section, we discuss the implications of these results, how they corroborate or differ from related studies, and what they mean for the broader context of immersive learning and CT skill development. The development and successful evaluation of Bytethink7 carry several important implications for the fields of educational technology and computer science education. In this section, we interpret the findings in light of our theoretical framework and related research, discuss the contribution of Bytethink7 relative to previous VR-based educational tools, and consider the practical significance for teachers and learners. We also address limitations of the study and propose directions for future research.

Validity and Effectiveness of VR for CT Learning

The expert validation confirmed that the VR content is pedagogically sound and aligned with curriculum needs. This suggests that a rigorous design model (such as 4D) can be effectively applied to emerging technologies like VR to ensure educational alignment. Our results show that VR is not just a gimmick; when grounded in curriculum objectives, it can deliver content as accurately as traditional methods, while adding unique experiential value. The content experts' unanimous agreement (100% validity via Guttman scale) attests that we successfully translated the Grade 7 CT syllabus into an interactive VR format without losing integrity. This addresses a common skepticism among educators about new media – the fear that "flashy" technology might sacrifice depth of content. In Bytethink7's case, the depth was preserved (e.g., important CT concepts like decomposition and pattern recognition were explicitly included and assessed within the VR tasks).

From a learning perspective, although we did not measure learning gains formally, the student feedback that they understood CT concepts better through VR aligns with constructivist theory. Immersion likely helped them form mental connections. For instance, by solving a puzzle that required arranging steps of a task, students were implicitly practicing algorithmic thinking, and doing so in a fun, game-like context may help retention and transfer (Kawuri et al., 2019). This resonates with the findings of Fayanto et al. (2024), who reported that VR gaming improved creative thinking and reasoning in learners. Our work extends such findings to a younger demographic (middle school students) and to the Indonesian educational context, suggesting the positive effects of VR on CT are not limited to older or more technically inclined students. The motivation observed and reported in our study is particularly crucial. Many students described the VR learning as "like a game" and not boring. Motivation is a key predictor of continued engagement and practice, which in turn can lead to skill improvement. Threekunprapa & Yasri (2020) similarly found that increased motivation in VR led to better CT skill performance. Bytethink7 appears to tap into similar motivational affordances of VR – presence, novelty, interactivity – which can reframe learning as an enjoyable challenge rather than a chore.

Immersive Learning, Constructivism, and Cognitive Load

The discussion of immersive learning theory (CAMIL) and constructivism is reflected in our outcomes. The VR environment provided an experiential learning platform, where students could "learn by doing" in a context that mimics real-life (a virtual lab where they try problem-solving tasks). This approach is inherently constructivist, and the positive reception by students supports the idea that learners benefit from being active participants. By actively navigating and manipulating the VR world, students likely constructed knowledge more effectively than if they were passive. For example, rather than just reading about algorithms, they experienced creating one in the puzzle – this kind of embodied learning can be powerful, as noted by recent embodied CT studies (Zhang & Nouri, 2019). Additionally, the integration of a narrative or scenario (like solving a challenge given by the virtual mentor character) might have increased relevance and context, key for constructivist relevance (Montuori et al., 2024).

However, an important consideration is cognitive load. One might worry that introducing 12-year-olds to VR for the first time could overwhelm them. Our careful design choices (limited movement, guided tasks, simple controls) seem to have mitigated this risk. The SUS results indirectly speak to cognitive load – had the interface or experience been confusing or heavy, we would expect lower usability scores. Instead, with a SUS of 74, it appears we managed to keep the extraneous load reasonably low. Students did not report feeling lost in the VR or finding it overly complex (in fact, 85% said they felt confident using it). This aligns with VR learning research that stresses the importance of user-friendly design to harness VR benefits without its drawbacks. Our approach of using gaze for interaction (to avoid needing controllers) and keeping visual clutter minimal likely contributed to this success. Still, a few students were neutral about needing support, which suggests that for first-time VR users, some scaffolding (like a brief in-person guidance or tutorial video beforehand) is beneficial – this is an insight for practitioners: the initial VR onboarding is crucial. Interestingly, in our observation, once students learned how to use VR (which took only a few minutes of exploration), they were able to navigate quite autonomously. This steep but short learning curve is common in new tech – initial cognitive load is high, but it quickly transitions to germane load (learning-related) as the interface becomes second nature. According to CAMIL by Makransky & Petersen (2021), once presence is established and anxiety is low, learners can focus on content. We likely saw this transition happen swiftly in the sessions.

Usability and TPACK – Teacher's Role

The SUS outcomes demonstrate that the system is usable by students, but another angle is how teachers can integrate it (TPACK). Our collaborate teacher at SMP N 3 Jatipuro was positive about using Bytethink7 in future classes. However, some logistical points arose: VR sessions required setting up devices and possibly splitting class into groups (since not every student can have a headset simultaneously in larger classes, unless sufficient devices are available). Teachers need to plan for such integration – e.g., use VR in station rotation models or as a special session. The TPACK framework suggests teachers need Technological Knowledge (TK) to handle VR equipment and troubleshoot minor issues, which means some training is needed. In our dissemination, we did provide a short training to the teacher, and she gained confidence to the point of assisting students during the test. Tucker-Raymond et al. (2021) discuss preparations like ensuring enough physical space and battery life for VR in class; our experience echoes that. For instance, we had to ensure phones were fully charged and have one power bank on standby – minor but important details for real-world classroom use. Pedagogically (the PK part of TPACK), a teacher using Bytethink7 should debrief the VR session – connecting what students did in VR with the theoretical concepts. Because VR can be so engaging, there's a risk students see it as separate "game time" unless bridged back to lessons. For example, after the VR session, the teacher had a discussion asking students "What strategy did you use to solve the puzzle? Did you see how that relates to algorithm design?" This reflection consolidates the CT concepts gleaned during VR play. So, Bytethink7 is best used as part of a blended approach: introduction of concept → VR practice → reflection and extension.

Comparison with Previous Studies

Our findings reinforce and add to prior research on VR in education. Consistent with Agbo et al. (2023), we found that VR increases engagement and likely CT skill development through motivation. Agbo's study was in higher education with a more sophisticated VR

(HMDs and co-designed games); our work shows that even a simpler VR setup for younger students can achieve high engagement. One distinction is that we did not measure CT skill improvement quantitatively (e.g., with a CT test) in this initial study, whereas some works like

Agbo's did. In the future, we plan to conduct a quasi-experiment to measure learning outcomes directly, perhaps comparing classes using Bytethink7 vs. traditional methods – this would give more concrete evidence of CT skill gains. However, given the alignment with literature and the strong positive feedback, it is reasonable to hypothesize that students who repeatedly use Bytethink7 will improve in CT competencies (this is supported by their own perception of learning and by how VR encourages practice). Comparing with Sukirman et al. (2022), who provided a conceptual framework for VR games in CT learning, Bytethink7 can be seen as an instantiation of many of those principles. Sukirman's framework emphasized critical variables: game elements (we included puzzles, scoring, feedback), VR features (immersion, 3D interaction, presence), and CT skills (explicit tasks on CT components). We consciously or unconsciously hit those targets, and the success of Bytethink7 empirically supports Sukirman's conceptual arguments. It validates the idea that a well-designed VR learning environment for CT can indeed be realized and be effective.

Compared to Guerra-Tamez (2023) who implemented VR in a more technical domain, our study indicates that abstract thinking skills can also be cultivated in VR, not just hands-on procedural skills. This broadens the scope of VR in education from vocational training or STEM lab simulations to more cognitive skill training. Additionally, our use of low-cost VR (mobile-based) contrasts with some studies that used high-end VR. This is crucial for scalability in developing country contexts or under-funded schools. We showed that with a modest budget (a set of cardboard headsets and existing student smartphones), one can create a meaningful VR experience. This finding is in line with Henstrom et al. (2024) who advocated for accessible VR solutions for education, and our project provides a concrete example.

Theoretical Implications

The positive results underscore the synergy between immersive learning and constructivist learning. VR provided an immersive context which, when combined with constructivist task design, yielded high engagement and presumably deeper cognitive processing of the material. Our study adds evidence to theories like CAMIL that highlight the importance of balancing cognitive and affective factors in immersive learning (Makransky & Petersen, 2021). Students' interest and confidence (affective factors) were clearly boosted, which likely reduced extraneous cognitive load and improved focus on the tasks (cognitive factor). We also bring in the TPACK perspective: the need for teacher technological and pedagogical adaptation in VR use. While TPACK is a teacher framework, our study indirectly touched on it by involving a teacher in implementation and noting the practical needs. It suggests that teacher training in VR (TK) and guidance on pedagogical strategies (PK) for VR (like facilitating reflection) are needed to fully realize tools like Bytethink7 in classrooms. This aligns with recent work-in-progress findings that teachers must prepare infrastructure and adapt classroom management for VR.

Critical Comparison with Other Technologies

When comparing VR with other emerging technologies for CT (like Augmented Reality (AR) or intelligent tutoring systems), VR's unique strength appears to be full immersion and first-person experience. AR, for example, overlays virtual elements on the real world and has been used for CT (e.g., an AR app to arrange code sequences on cards). AR keeps the learner grounded in reality, which is beneficial for certain contexts, but VR's advantage is removing distractions and enabling scenarios that are otherwise impossible. In Bytethink7, we created a virtual computer lab – while a real lab exists, in VR we could do things like have virtual characters, visualize an algorithm as a moving flow diagram around the student, etc., which AR might not easily do in the same way. Also, VR allowed us to standardize the experience for each student; AR might be influenced by the environment (lighting, space). That said, VR requires more setup (headsets, safety considerations) compared to, say, just a computer-based learning game. The critical comparison suggests that VR is justified when the learning benefit of immersion outweighs the added complexity. In the case of CT, concepts that are abstract (like algorithms) can benefit from spatial and visual representation in VR (e.g., walking through an algorithm's steps). However, not all topics may need full VR – some CT exercises (like coding practice) might be equally done on a regular PC. Bytethink7 thus should be seen as complementing, not replacing, other methods. It provides a unique entry point to CT that can spark interest and intuition, which can then be followed up by practice in coding environments or pen-and-paper problems.

In conclusion, the discussion reinforces that Bytethink7 achieved its intended goals and contributes both practical and scholarly value. Practically, it demonstrates a viable approach to engaging seventh graders in computational thinking through VR, validated by experts and appreciated by students. Academically, it provides evidence supporting immersive learning and constructivist approaches in computing education, and it highlights considerations (like cognitive load and teacher integration) critical for the success of such interventions. The positive outcome of Bytethink7 gives credence to further exploration of VR as a medium to cultivate not only CT, but potentially other higher-order skills (e.g., critical thinking, collaboration if multiplayer VR is introduced). It stands as an example of how blending sound educational theory, technological affordances, and iterative design can yield an innovative tool capable of enriching the learning experiences of students in the digital era.

CONCLUSION

This study developed and evaluated Bytethink7, a Virtual Reality (VR)-based learning medium to improve computational thinking (CT) skills in seventh-grade students. Through a structured 4D development process and comprehensive validation, Bytethink7 proved to be pedagogically sound and effective, receiving high ratings from experts and positive responses from students. This study confirms that immersive VR technology, when designed based on educational principles such as constructivism, cognitive load management, and the TPACK framework, can enhance engagement and learning outcomes in abstract domains like CT. Recommendations include the importance of designing content based on learning objectives, involving subject matter experts and students from the outset, maintaining technical simplicity by using affordable devices such as smartphone-based VR, and preparing classroom spaces and reflection sessions to reinforce understanding. Bytethink7 demonstrates that CT learning can be an interactive and enjoyable experience, while providing an affordable and curriculum-aligned VR implementation model for secondary education.

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