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IMPACT OF VIRTUAL AGENTS AS A SOURCE OF FEEDBACK IN DIGITAL GAME-BASED LEARNING ON CHILDREN'S LEARNING AND MOTIVATION

Mukhaled Hamza Hussein Abass Al-Khafaji [1], Mohamed Shawky Hozaifa [2], Basant A. Alakabawy [3], Basma Alakabawy [4], Mohammed Alsuwailem[5], Esam Shawky Elzok[6*] and Ahmed Said Salem Elattar [7]

[1]Assistant Professor of Environment Pollution Department, College of Environment, Al-Qasim Green University, Babylon 51013, Iraq, mukhaled.hamza@environ.uoqasim.edu.iq, http://orcid.org/0009-0009-4960-5661
[2]Associate Professor of Educational Technology, Faculty of Specific Education - Menoufia University, Tala, Menoufiy,Egypt, ORCID: http://orcid.org/0009-0007-4509-2374 , mohamed.hozaifa@sed.menofia.edu.eg
[3] Associate Professor of Media and Children's Culture, Faculty of Early Childhood Education - Menoufia University, Shebin-Elkom, Menoufiy, Egypt, http://orcid.org/0009-0008-8263-0570, drbasantalakabawy@gmail.com
[4]Assistant Professor of Educational Technology, Faculty of Specific Education - Menoufia University, Menoufiy, Egypt, https://orcid.org/0009-0000-2991-2167, bosyalakabawy@yahoo.com
[5]Associate Professor, Faculty of Education - Qassim University Al-Qassim, Kingdom of Saudi Arabia, https://orcid.org/0009-0006-0485-3192, M.alsuwailem@qu.edu.sa
[6] Professor of Educational Technology, Faculty of Specific Education – Menoufia University, Shebin-Elkom, Menoufiy, Egypt, http://orcid.org/0009-0006-4129-3075, essam.shebl@sed.menofia.edu.eg
[7]Associate Professor of Educational Technology Department of Educational Technology- Faculty of Specific Education- Menoufia University Shebin El-Kom, Menoufia Governorate, Egypt. Email: ahmed.elatar@sed.menofia.edu.eg Orcid ID: https://orcid.org/0000-0001-9792-4354

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Corresponding Author: Esam Shawky Elzok (essam.shebl@sed.menofia.edu.eg)

ABSTRACT

Virtual agents (VAs) are a promising technology. Recent technological advances have enabled researchers to build human-like agents to provide an interactive learning environment. However, the question of how virtual agent (VA) persona representation can enhance children's motivation and learning remains unanswered, highlighting the need to investigate the impact of integrating two VA characters into a digital game-based learning (DGBL) environment for children's learning of scientific concepts (SC) and motivation. A randomized controlled trial was conducted on 38 kindergarten children (aged 4–6). They were randomly assigned to either a DGBL group supported by a VA highly human-like (HHL) or a DGBL group supported by a VA less human-like (LHL). They participated in 35-minute play sessions over six weeks. The VAs provided real-time corrective feedback, explanations, and question-and-answer sessions. The results indicate that children in the DGBL+VA (HHL) group achieved greater improvements in learning scientific concepts and significantly higher

motivational intensity compared to the DGBL + VA (LHL) group. Additionally, the DGBL + VA (HHL) group demonstrated improved retention of broader learning, including significant increases in both extrinsic and intrinsic motivation. The results revealed a relationship between SC acquisition and motivation when children interacted with the VA-supported DGBL environment. The results revealed that children supported by the VA (HHL) demonstrated more organized error correction, greater immersion, and active engagement. These findings highlight the ways in which VAs enhance the functions of DGBL in children's SC learning.

KEYWORDS: Virtual agents, feedback, motivation, children's learning, Digital Game-Based Learning.

1. INTRODUCTION

Digital game-based learning (DGBL) has evolved into an integral part of educational technology use. The integration of virtual agents (VAs) to facilitate educational and social interactions with children has become a prevalent trend in digital learning environments. Providing feedback has become a core function of VAs as a key means of maintaining children's motivation and enhancing their learning (Bhutoria, 2022). Feedback to VAs can be classified into cognitive and affective feedback (Lu & Law, 2012). With the growing popularity of DGBL, researchers are paying great attention to exploring ways and methods to maintain children's motivation while learning (Nadeem et al., 2023). Especially for children, due to the difficulty of maintaining their motivation throughout the DGBL process (Ronimus et al., 2014; Horovitz & Mayer, 2021), there is a need to develop and utilize more detailed educational designs for virtual agent(VA) characters. Several studies have found inconsistent effects of VAs feedback on children's learning motivation. Some studies have confirmed the advantage of VA feedback in stimulating children's positive emotions and motivation (Guo et al., 2014; 2015; 2016; Wang et al., 2019). While some studies have found no effect of VA feedback on children's motivational states (Beege et al., 2020; Liew et al., 2016). In addition, there is growing evidence that VA feedback has mixed effects on learning performance. Many studies have found positive effects of feedback on learning performance (Oker et al., 2020; Wang et al., 2022). On the other hand, the results of some studies have shown no effect of VA feedback on learners' learning (Beege et al., 2020; Horovitz & Mayer, 2021; Guo & Goh, 2016).

This may be due to the presence of mediating variables or conditions for the conflicting effects of visual design methods applied in multimedia learning such as DGBL (Mayer, 2010). Investigating potential intermediate conditions not only helps in the rational use of these methods, but also has high theoretical and applied value (Wang et al., 2022). Therefore, the research explores the mediating variables that can influence the effectiveness of a VA, including the characteristics of the VA as a source of feedback (Momen et al., 2016). The research will focus on investigating the effects of two VAs representations: a highly human-like(HHL) VA and a less human-like(LHL) VA on children's learning and motivation(Tuah et al., 2016). The primary objective of the current study is to evaluate the effects of feedback from a virtual agent (HHL) to a virtual agent (LHL) on children's learning and motivation. Furthermore, given that Vas are beneficial to learning in some situations but unfavorable to learning in others, it is necessary to investigate the moderating roles of specific characteristics of VAs or other external mediating variables (e.g., learner characteristics, learning materials, learning duration, etc.) that may influence learning effects (Gui et al., 2023; Sinatra et al., 2021), thus providing suggestions on how to design an effective VA character. In particular, many experimental studies still have inconsistent conclusions about whether the VA character as a source of feedback is strongly effective in increasing positive emotions, motivation in children and enhancing learning performance (Segaran et al., 2021; Alakabawy, 2024). Although there are some studies that help us understand the impact of VA representation in digital learning settings (Castro-Alonso et al., 2021; Davis, 2018), little research has focused directly on VAs to investigate how feedback and support from VAs affect children's motivational states and learning performance (Levac & Lu, 2019). The current research contributes to a deeper understanding of the importance of feedback from VA representations in children's learning, providing researchers with a more objective perspective for understanding VA representations (HHL vs. LHL).

2. LITERATURE REVIEW

2.1. Dgbl, Children's Motivation, And Learning Scientific Concepts

DGBL has evolved into an integral part of the educational use of information and communication technology. DGBL is a rapidly expanding field, especially in early childhood (Manesis, 2020). This is primarily because it is one of the most popular forms of learning for children (Schmitt et al., 2018). The results of several studies (Vankus, 2021; Kokkalia et al., 2017; Xiong et al., 2022; Hui & Mahmud, 2023) have indicated that DGBL enhances children's learning, social interactions, problem-solving, creative thinking, memory, and hand-eye coordination skills. Adipat et al., (2021) note that when children complete a DGBL activity appropriately, they often take responsibility for their decisions and thus become more independent in their actions and learning. In terms of enhancing conceptual understanding, DGBL has been shown to facilitate the acquisition of scientific concepts SC by providing a contextual and interactive learning environment that improves conceptual cognitive processing (Coleman & Money, 2020; Hui & Mahmud, 2023). By providing a more authentic, multi-sensory, and motor-rich context, DGBL can

enhance the efficiency of learning SC, enabling children to interact with concepts in a more realistic, comprehensive, and integrated way (Parker et al., 2022). The digital gaming environment provides valuable opportunities for children to engage in concept learning by providing feedback on their behaviors and decisions, which encourages active interpretation of the concept through their knowledge of SC and the embodied context of the game (Arztmann et al., 2022; Gui et al., 2023). DGBL has been shown to support concept learning across children's different proficiency levels (Alotaibi, 2024; Behnamnia et al., 2023). In addition, research suggests that low-achieving children particularly benefit from game-based scenarios, showing higher engagement and actively participating in learning concepts (Smiderle et al., 2020).

On the other hand, well-designed DGBL environments can integrate appropriate pedagogical tasks that promote meaningful concept learning (Theofylaktos et al., 2018), as research shows that embodied learning through physical interaction in virtual environments enhances concept understanding and retention (Fuhrman et al., 2021). Based on these advantages, DGBL has been widely adopted in children's learning, with empirical studies proving its effectiveness in improving multiple competencies (Hwa, 2018). For example, children participating in online role-playing games outperformed their peers in traditional classrooms in many skills (Xu et al., 2023A). Similarly, research indicates that children who combine practice exercises with game-based activities achieve better pronunciation scores than those who rely solely on practice exercises, highlighting the added value of interactive and immersive learning experiences (Wouters & van Oostendorp, 2013).

In addition to the cognitive benefits of learning concepts, DGBL has been shown to enhance children's enjoyment and interest, creating an engaging and stimulating learning environment (Zhou, 2024). By creating a fun and low-stress environment, DGBL fosters a positive learning climate that enhances motivation and engagement (Rodríguez-Ferrer et al., 2023). Researches indicate that DGBL can enhance children's confidence in learning concepts and increase their self-efficacy (Lu et al., 2011). While enhancing motivation, maintaining attention, and promoting learning retention in an enjoyable way (Anyaegbu et al., 2012), emotional factors, such as anxiety and the desire to communicate, play a crucial role in children's acquisition of concepts (Graziano et al., 2007). Research has shown that DGBL is an effective tool in reducing children's anxiety and increasing their motivation to learn concepts (Hung et al., 2014). By lowering emotional barriers, DGBL promotes a comfortable experience of learning SC through interactive play, which encourages a strong desire to communicate (Alim et al., 2022). It is worth noting that children with severe anxiety appear to benefit most from DGBL, as their game performance is positively correlated with learning outcomes (Yang et al., 2018).

Published studies highlight the significant challenges and monotony associated with children's learning of SC. Early childhood education tends to focus heavily on developing literacy skills, sometimes at the expense of developing SC (NSTA, 2014; Mantana et al., 2014). To achieve proficiency, (1) children must engage in making concrete and explicit connections between information texts they read and experiential learning activities related to SC (Shabiralyani et al., 2015). (2) Deepening children's conceptual knowledge, including relationships between main ideas and logical thinking skills about concepts (Ates & Cataloglu, 2007). (3) Selecting high-quality informational texts that are consistent with their goals for developing children's SC (Pentimonti et al., 2010). (4) Teachers should create rich science learning experiences in diverse supportive contexts, including informational texts, so that young children have the opportunities they need to deepen their understanding of concepts in early childhood. Learning concepts in early childhood establishes foundational knowledge about our world, which continues to support learning throughout school and into adulthood (Hoffman et al., 2015). Anxiety about acquiring SC exacerbates these challenges, with many teachers reporting high levels of anxiety when teaching children SC (Christensen & Osgood, 2023). Traditional learning methods, which often rely on repetitive drills and memorization, fail to provide children with authentic interactive environments, limiting their ability to apply SC in context and leading to decreased motivation, making it difficult for children to maintain their enthusiasm unless they are exceptionally motivated or highly disciplined (Habgood & Ainsworth, 2011).

DGBL has emerged as a promising approach for providing a dynamic, learner-centered approach that transforms the learning of SC into an engaging and effective process. It addresses the limitations of traditional methods while promoting sustained motivation and self-efficacy (Videnovik et al., 2023; Lampropoulos, 2023A). DGBL allows children to naturally engage in repetitive practice without perceiving the monotony of repetition, which

alleviates boredom and enhances learning efficiency and effectiveness (Anastasiadis et al., 2018). At the same time, DGBL enhances understanding through contextual scenarios and engaging gameplay, which fosters positive emotional states, stimulates interest, and creates an immersive and imaginative learning space that makes the acquisition of SC effective and enjoyable (Beavis et al., 2014; Erhel & Jamet, 2013). According to Naidoo's (2023) systematic review, DGBL facilitates children's learning in areas such as acquiring SC, while enhancing motivation, confidence, and learner satisfaction. For example, games incorporate key gameplay elements—context, objectives, feedback, and interactivity—to create a more engaging and motivating learning experience than traditional methods of learning SC. Results showed that both the scenario-based digital game and the interactive online lesson improved learners' knowledge, but the game-based environment led to significantly higher levels of motivation (Hellín et al., 2023; Alexiou & Schippers, 2018). Furthermore, interactive feedback that considers learners' self-esteem fosters a positive learning climate, which enhances children's confidence and willingness to participate (Câmpean et al., 2024; Monteiro et al., 2018). Empirical evidence supports the effectiveness of digital game-based learning for early childhood learning, with post-test results showing significant improvements in children's proficiency compared to pre-test results (Tahir & Wang, 2022; All et al., 2016). In addition, incorporating interactive elements, such as VAs, not only enriches the learning experience but also enhances children's understanding and confidence in learning SC (Cinar et al., 2024; Errabo et al., 2024). However, despite the growing popularity of DGBL in concept teaching, most studies of DGBL have focused on linguistic concepts and vocabulary, with relatively fewer studies exploring its application in children's learning of SC (Vnucko & Klimova, 2023). Meanwhile, according to Mahmood's study of games for children's learning, although the role of DGBL in enhancing motivation among children is increasingly recognized, most studies focus primarily on qualitative descriptions of their motivational effects, with few systematic attempts to measure their impact on children's motivation (Mahmood et al., 2019).

2.2. Virtual Agents as a Source af Feedback to Increase Children's Motivation and Learning

A key feature of DGBL systems is their ability to provide immediate, context-aware feedback, which supports children's self-directed learning (Alotaibi, 2024). Explicit and detailed corrective feedback helps children identify and correct errors by providing linguistic explanations or the correct formulation immediately after the error occurs (Lira-Gonzales et al., 2024). Research indicates that VA-assisted feedback tools outperform traditional teacher-led methods in improving children's learning and skills by providing immediate, unbiased, and detailed corrections, which supports enhanced knowledge acquisition (Gu et al. 2023; Bernard et al., 2019; Hieke et al., 2018; Davis et al., 2022). A VA is a character that may be highly human-like (HHL) or less human-like (LHL) embedded in software displays, aiming to influence learners' emotional experiences and learning performance by providing feedback (Dirin & Laine, 2023). Many studies have been conducted on designing learning materials to be visually appealing using methods (e.g., colors, shapes, and metaphors) to stimulate learners' motivation and thus improve learning (Bobek & Tversky, 2016; Wang et al., 2021 ; Plass et al., 2014). On the other hand, researchers have sought to identify the roles of VAs in the learning process (Lawson et al., 2021; Lawson & Mayer, 2022; Heidig & Clarebout, 2011; Jin, 2010). In such roles, an important design consideration is to add a representation of the VA character in DGBL programs, and to know the extent of its impact on the learning experiences and outcomes of learners (Zhang et al., 2023).

Although there is a discrepancy in the results of experimental studies on whether VAs are strongly effective in increasing motivation and enhancing learning outcomes in children (Dai et al., 2022; Yue et al., 2022). These conflicting results raise questions about the representation of the persona of the VA, supporting the call to investigate and quantify the effects of VA variables. Liew et al.'s (2017) study found that a motivated VA (through voice tone, facial expressions, gestures, and feedback) increases intrinsic motivation and improves learning performance of undergraduate students with C programming algorithm outputs. While Shiban et al.'s (2015) study found that the appearance of a VA had an effect on increasing student motivation, without having any effect on performance. Studies (Clark et al., 2016; Taub et al., 2020) also found that the presence of VAs does not enhance learning. These conflicting results raise the need for further research into which specific features of the VA may contribute to enhanced learning and motivation (Major, et al., 2021).

The ability of VA persona representations (HHL vs. LHL) to increase motivation and enhance learning can be explained in light of several theories. Affective response theory, which suggests that the verbal and

nonverbal communications of a VA may influence children's behaviors (Bhutoria, 2022; Baylor & Kim, 2009). Accordingly, VA character representation can play a role in guiding and encouraging children by increasing their intrinsic motivation, leading to better learning outcomes (Hahn et al., 2020). The cognitive theory of multimedia learning (CTML) (Mayer, 2014), which suggests that increased learning is associated with increased or decreased cognitive engagement through the activation of motivational emotional states (Mutlu-Bayraktar, 2024). Social presence theory, which shows that children will have a more positive and enthusiastic experience of the learning process, when they perceive the presence of a VA in the interaction interface of a DGBL program (Oh et al., 2018; Anne et al., 2021). In light of this, when children perceive a VA persona (HHL) it will provide them with a stimulating experience of the learning process versus a VA persona (LHL). In this context, the results of the Horovitz and Mayer (2021) study indicated that participants' intrinsic motivation increased with the presence of a human-like VA compared to a non-human-like agent. While cognitive load theory suggests that the memory resources of a VA (HHL) are limited in terms of storage and learning duration (de Jong, 2010). Accordingly, the use of a VA (HHL) may increase children's external cognitive load, which may affect their learning (Schneider et al., 2021). In this, the VA (HHL) may distract children from relevant information, according to interference theory (Pan & Hamilton, 2018), which may affect their performance and learning. In this context, the results of studies indicated that learners experienced high mental loads and performed poorly when learning from a semi-human educational agent (Chang et al., 2022; Florian et al., 2020).

On the other hand, CTML theory (Mayer, 2024) assumes that learner characteristics may modify the effectiveness of instructional design (Çeken & Taşkın, 2022). The characteristics of the participants in the current research refer to children in kindergarten, aged 4:6 years. Both (Dinçer & Doğanay 2017; Xu et al., 2023) indicated that VAs have effects on learning outcomes depending on the educational level. Therefore, younger children may see a higher need for a VA (LHL) to guide and enhance their learning (Girouard-Hallam & Danovitch, 2023). Schneider et al., (2019) found that younger children experienced high cognitive load in the high teacher likeness condition, becoming distracted, which affected their learning. Therefore, a VA (LHL) may be a better learning support for increasing motivation than a HHL agent (Van Pinxteren et al., 2020). The VA, regardless of its representation, may provide benefits to children supported by emotional contagion theory (Herrando & Constantinides, 2021). According to the theory, children's state may be automatically influenced by the feedback of the VA depending on the representation of the persona (HHL vs. LHL) in electronic environments (Park & Catrambone, 2021; Bylieva et al., 2021). This means that when interacting with a VA persona, children may exhibit emotional states, and are more likely to experience more positive emotions and higher motivation (Tsai et al., 2012; Cadet et al., 2022). In addition, affective response theory suggests that children's verbal and nonverbal cues are closely related to teachers' affective response (Wang et al., 2022A ; Marije et al., 2013 ; Frenzel et al., 2021). his means that VA persona feedback can enhance children's emotional responses and thus improve their intrinsic motivation, which is reflected in learning outcomes (Tal et al., 2024; Lang et al., 2022). This is consistent with what CTML theory suggests that feedback from the VA will lead to changes in children's motivation to learn (Lipnevich & Panadero, 2021). However, a study by Beege et al., (2020) compared an enthusiastic VA with a neutral agent and found that the enthusiastic agent did not induce positive emotions in learners. Liew et al., (2016) also found that a VA with a smiling face led to less positive feelings and lower intrinsic motivation than an agent with a neutral face in an e-learning environment. In this context, the different effects of the VA's persona representation on motivation can be explained by the uncanny valley theory (Nidhi et al., 2022), which suggests that when the VA closely resembles a human, children may experience strangeness and less emotional excitement (Angela & Robin, 2014). Therefore, Frechette and Moreno (2010) pointed out the need to investigate learners' expectations of VAs, as it may negatively affect children's cognitive and motivational processing.

Moreover, the visual representation of VA personas can have a significant impact on students' motivation, emotions, and learning (Shiban et al., 2015). Because less human-like VAs feature simple and engaging visual representations, they have attracted children as well as college students, especially males (Straßmann et al., 2020; Ayedoun & Tokumaru, 2022; Barker, 2019). Kim and Wei (2011) stated that for a VA to be effective as a source of feedback, its character representation must be chosen correctly, especially for preschool children. This supports the review conducted by Dai et al. (2022) in the period (2010-2021) which indicated that despite

the reported successes of VAs, the results of studies did not provide a fairly conclusive picture of the extent to which the representation of the VA persona contributes to an effective learning experience.

Given the advantages of DGBL in providing personalized and adaptive learning experiences, studies highlight the transformative potential of combining VA personas and DGBL, as their convergence can enhance interactive, immersive, and personalized learning experiences for children (Lampropoulos, 2023). This dynamic synergy between VAs and DGBL is considered to enable children's learning by providing immediate and adaptive feedback and interactions that adjust to children's progress (Jackson et al., 2015), enable timely error correction, and promote positive learning behaviors, such as increased engagement and motivation, while effectively supporting information acquisition and mastery (Khine, 2024; Alam, 2023). Experimental evidence suggests that game-based learning with the help of VAs in science learning enhanced students' learning behaviors, self-motivation, and perceived competence, while reducing cognitive load. Students supported by VAs outperformed those using game-based learning alone, reporting less mental load and more effective learning behaviors (Chang et al., 2018; Chen & Chang, 2024). In scientific concept learning contexts, DGBL typically provides immediate error correction, which may be less effective in complex unit content; however, incorporating DGBL has been shown to be particularly beneficial for children with low intrinsic motivation and self-efficacy (Ronimus et al., 2014; Liu & Hwang, 2024). VAs, supported by feedback, allow children to communicate their ideas more naturally, directing adaptive responses and interactions during learning, while DGBL transforms the learning process into an interactive and stimulating experience, helping children maintain interest and persistence in developing their knowledge (Khan et al., 2021).

2.3. Current study

Building on extensive studies on DGBL for children's learning and the role of VAs in science education, this study seeks to investigate the integration of two character representations (HHL vs. LHL) of VAs within a DGBL environment for children's learning of SC. Previous research has demonstrated that DGBL creates immersive, interactive, and context-rich learning experiences that enhance scientific and affective concept outcomes (Zheng et al., 2023). Meanwhile, VAs-using feedback mechanisms-provide real-time personalized error correction and reinforce positive learning behaviors (Liao et al., 2024). Recent studies indicate that the convergence of VAs and DGBL not only enriches the learning experience but also supports more effective skill acquisition and increases children's motivation (Erhel & Jamet, 2013; Chen & Tu, 2021). Despite these promising developments, there remains a research gap regarding the specific impact of digital game-based learning with the help of two VA representations (HHL vs. LHL) on children's learning of scientific concepts and motivational factors. To address this gap, this study poses the following research questions:

1. How will representation of VAs (HHL vs. LHL) as a source of feedback affect children's learning?
2. To what extent does the representation of VAs (HHL vs. LHL) as a source of feedback affect children's motivation?
3. To what extent does the representation of VAs (HHL vs. LHL) as a source of feedback affect learning retention?
4. What is the relationship between motivation and learning of SC for children in the two study groups (DGBL+ HHL) and (DGBL + LHL)?

3. METHODOLOGY

3.1. Design & Participants

A quantitative research methodology was used. We adopted an experimental design for a randomized controlled trial among participants, using two models of DGBL programs. The first program used a VA representation with a HHL persona; the second program used a VA representation with a LHL persona. To investigate the effect of VA persona representation as a source of feedback on children's motivation and learning in an educational context. To investigate the impact of VA representation as a source of feedback on children's motivation and learning in an educational context, we combined digital content, exercises, and practices with immediate feedback from the VA. The content of the two programs included scientific concepts for kindergarten children related to: organisms, human senses, food chain, and characteristics of marine organisms (Campbell et al., 2015). We followed established guidelines for the two randomized trials. We adhered to the Consolidated Reporting Standards for Trials (Falci & Marques, 2015; Schulz et al., 2010) to ensure clarity of reporting and data structure. We incorporated recommendations from Higgins et al. (2023) for accurate bias assessment and

internal validity analysis. We also used a tool to evaluate the model's external validity and analyze the generalizability and replicability of our findings (Khorsan & Crawford, 2014).These assessments are critical to establishing the internal and external validity of the data, ultimately enhancing the quality of experimental research and reporting.

The participants included 38 Egyptian children (25 girls, 65.78%; 13 boys, 34.22%), aged 4–6 years (mean = 5.12; standard deviation = 0.79). They are all enrolled in the same preschool (kindergarten class) with the same teacher. The sample was from Salah Khattab Kindergarten in Menoufia Governorate, Egypt. They were randomly assigned to two experimental groups. None of the children had previously interacted with or learned using game-based educational software. Regarding educational content related to scientific concepts, teachers reported that children were rarely exposed to these concepts in the traditional abstract manner, and there were no DGBL educational programs available to train them. There were no interactive educational resources available for studying scientific concepts, such as images, videos, animations, or simulations. Teachers indicated that the focus at this stage was on developing the child's language and mathematical skills rather than scientific and biological skills (Darling-Hammond et al., 2023). All children answered the pre-, post-, retention test questions on the Illustrated achievement test. There were no statistically significant differences between the children of the two groups before exposure to the two processors, T =. 785, P =. 437. The teacher recorded her observations about the child's interactions during learning through a motivation questionnaire. Teachers completed the motivation questionnaire for all children. Children are normal, all of whom have natural eyesight or medical glasses. The approval of the educational administration and the teachers has been obtained. Figure1. shows the experimental design of the research.

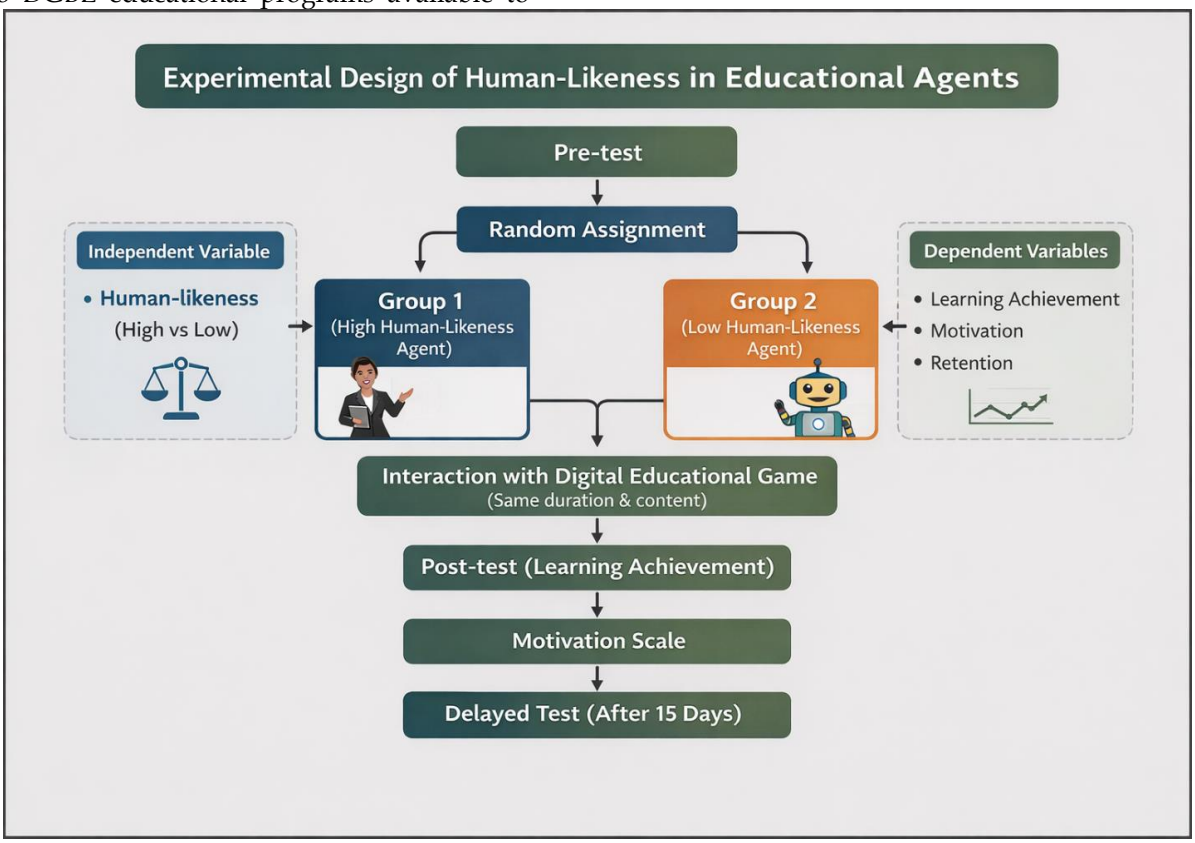

Fig 1: Research Experiment Design

Children have the skills needed to use computer and relevant technologies efficiently, given the spread of mobile devices that belong to some children or parents (Sharara, 2023). There are several reasons behind the low achievement of children in scientific concepts. First, kindergarten learning processes depend more on reading and writing activities than learning activities associated with scientific concepts (NSTA, 2014; Mantana et al., 2014). What is available in educational environments for children is only some simple activities that cannot learn scientific concepts. Teachers rely on traditional methods of explanation and speech (Hu, 2024). Kindergarten lacks educational subjects related to

scientific concepts. Teachers believe that teaching scientific concepts in early childhood requires effort, due to the characteristics of their associated growth stage, in which they may suffer from mental insufficiency, and weak sympathetic learning from experience. (Van Ijzndoorn et al., 2011). Second, when looking at the social and cultural background of children, it turns out that the families of these children live in a civilian - Shabin Al -Kom, Menoufia Governorate - economically weak. This may be due to the preoccupation of parents and the heavy burden on mothers in following up on their children in the preschool stage (Sharara, 2023; Alakabawy& Elzok, 2025). In the interviews that we had, teachers and administrators working in kindergarten confirmed these reasons. The main factor of this research is that the representation of the VA in the learning programs based on digital games in learning will be more important for children at this early stage (Alotaibi, 2024; Lamrani & Abdulwahid, 2019).

3.2. Measurement tools

Data were obtained through two measurement tools: Illustrated achievement test (IAT), covering the content of SC for kindergarten children (organisms, human senses, food chain, and characteristics of marine organisms). Motivation scale (MS) to measure children's attitudes towards the DGBL according to the representation of VA in the interaction interface. The two researchers prepared an IAT for SC in cooperation with the teachers. Preparing test questions according to the goals and achievements of the early childhood program. It consisted of 36 multiple-choice items. After preparing the Illustrated test with the help of the teachers to verify its validity, it was presented to a group of experts in curricula and teaching methods for early childhood. The experts commented on the suitability of the Illustrated achievement test items for children at this age. The experimental scheme for the prepared IAT was applied to 15 first-grade children (aged between 6 and 7 years). Test stability was calculated using the Guttman Split-Half Coefficient. Reliability coefficient was found to be .84. The reliability coefficient obtained is sufficient for IAT. For the MS, a four-point Likert scale was applied (always 4, often 3, sometimes 2, rarely 1). A number of studies were consulted to prepare Motivation scale statements (Nadeem, et al., 2023; Alsawaier, 2018). Scale consists of 15 items. The developed MS was applied to both groups. The scoring system used to evaluate the scale results was based on the teacher's observation of each child. Cronbach alpha was used to measure the reliability of the scale. The result was .86. This result of the reliability coefficient is appropriate for the Motivation scale.

3.3. Materials

To conduct this research, we created two versions of a DGBL environment, each corresponding to each group session. Each version includes learning content for children's science concepts, such as videos, animations, and training activities, within different study topics with different themes. Within both groups, participants (children) were expected to follow specific behaviors: 1) begin the course; 2) begin the video lesson; 3) complete the lesson; 4) provide responses to lesson exercises; 5) receive feedback from the VA based on their persona representation (HHL/LHL); complete the modules; and 7) conclude the lessons. These expected behaviors formed the basis for rewarding children participating in the digital learning environment under various game element settings, with the VA assigned to provide feedback in the event of a correct or incorrect response. The design process of interactive games involved manipulating variables using a digital system to encourage participants to engage in better and more engaging behaviors (Coelho & Abreu, 2023; Plass et al., 2015). For example, the virtual agent (HHL/LHL) was expected to encourage children to put in effort in providing accurate answers to exercises rather than resorting to guesswork, as errors lead to reduced or no rewards from the VA. In the first version, children were able to receive feedback from a VA (HHL). In the second version, children were able to receive feedback from a VA (LHL), as shown in Figure 2.

Fig. 2 left: The representation of the VA (HHL). Right: A representation of the VA (LHL).

Both versions were developed based on the procedures of the ADDIE model. The ADDIE model is a valuable source of additional information by providing good teaching practices (Spatioti et al., 2022). The ADDIE model is applicable to meeting the diverse teaching requirements of all online

educational environments. In this study, we note that good learning practices include multimedia presentations, feedback, a variety of interactive exercises or activities, a shared (individualized) learning strategy, and the role of teachers as guidance and monitoring (Li & Cheong, 2023).

DGBL software for the first group.

Use a HHL representation of VA when designing the DGBL. A social model of a teacher similar to kindergarten teachers was chosen, Figure 2. She has characteristics that mimic a kindergarten teacher in terms of (general appearance, clothing, age). The HHL interface agent interacts with voice, text, facial expressions, and gestures. Agent's voice is a pre-recorded human voice for a parameter. In this type of interaction, virtual agent talks to the child through cases of correct responding, incorrect responding, and retries.

DGBL software for the second group.

A cartoon character (LHL), shown in Figure 2, was used as a representation of the VA in the interface. One of the famous cartoon characters beloved by children - in Egyptian society - was chosen, which is SpongeBob, Figure 2. This was done by showing a number of cartoon characters to the children of the survey sample. Character SpongeBob received a rating of 85% for children's. SpongeBob interacts with children with voice, text, expressions and gestures. The agent's voice is a pre-recorded SpongeBob voice.

3.4. Procedures

First, the two programs were installed for use by both groups on laboratory computers. The following were taken into account: screen size (15-inch screen; screen resolution 1600 × 900), the children's distance from the screen (approximately 60 cm), and the children's viewing angle (approximately 48 degrees in width and 28 degrees in height). The IAT was administered to the children as a pretest. The two groups were confirmed to be equivalent a priori, T =. 785, P =. 437. Children in each group began interacting with the DGBL program developed for them. The children learned SC for six weeks. Learning took place over a period of 35 minutes per group/week. The experiment was conducted under the supervision of the class teacher, as shown in Figure 3.

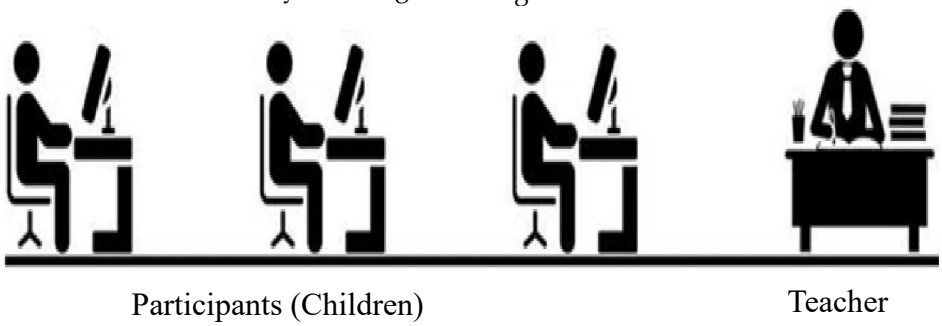

Fig 3: Setting up a group session.

Second, starting in the second week, the kindergarten teacher was asked to observe each child as they interacted with the program. These observations were linked to a motivation scale. The teacher was asked to record final observations for both groups in the sixth week on the motivation scale. Teachers reported changes in the children's behaviors and actions while using the two programs based on the VA representations. The Illustrated Achievement Test (IAT) was administered as a post-test to both groups. The same IAT was re-administered to both research groups to determine the effectiveness of the VA representation (HHL/LHL) on learning retention.

3.5. Data Analysis

After the experimental activities were completed, the data were monitored and processed using SPSS version 23. Quantitative descriptive statistics were calculated for the two groups. Children's pre-test IAT scores were compared with their post-test scores to determine the effect of the HHL/LHL virtual agent persona representation. A two-group independent-paired t-test was used. Given that there were two experimental groups, and there was equivalence between the children in both groups before and after the test (Xu et al., 2017). To determine whether there was a difference in the effect of the virtual agent on post-test scores and retention test scores, an independent two-group t-test was conducted to analyze the differences between the mean scores of the two groups on the motivation scale. A significance level of P≥.05 was considered.

4. RESULTS

Results of quantitative descriptive statistics.

To answer the research questions regarding the impact of HHL/LHL virtual agent representation on

the two groups, Table 1 presents the combined descriptive statistics for the two treatments.

Table 1: Descriptive Statistics for Each Learning Environment.

DGBL	N	Learning Test	Illustrated achievement test		Motivation Scale	
			M	*SD.*	*M*	*SD.*
G1: HHL	20	Pretest	12.10	1.86	-	-
		Posttest	32.50	1.46	53.50	2.43
		Retention	31.35	1.66	-	-
G2: LHL	18	Pretest	11.66	1.49	-	-
		Posttest	30.00	2.35	50.33	2.35
		Retention	28.94	1.21	-	-

Table 1 presents descriptive statistics for the pre, post-, retention IAT scores, and motivation scale for both groups (DGBL+HHL and DGBL+LHL). The table shows that the mean scores on the post- and retention IAT for both groups were higher than the mean scores on the pre-IAT. The mean score for the DGBL+HHL group on the pre-IAT was M = 12.10 (SD = 1.86); the mean score for the post-IAT was M = 32.50 (SD = 1.46); and the mean score for retention was M = 31.35 (SD = 1.66). The mean score for the DGBL+LHL group on the pre-IAT was M = 11.66 (SD = 1.49); and the mean score for the post-IAT was M = 30.00 (SD = 2.35). The mean retention score was M = 28.49 (SD = 1.21). The DGBL+HHL group showed significant improvements in post-test retention compared to the DGBL+LHL group. The table also shows that the DGBL+HHL group had higher mean scores on the motivation subscale compared to the DGBL+LHL group. The mean motivation subscale score for the DGBL+HHL group was M = 53.50 (SD = 2.43); while the mean motivation subscale score for the DGBL+LHL group was M = 50.33 (SD = 2.35). This shows greater interaction and participation of the DGBL+HHL group compared to the DGBL+LHL group.

1. How will representing the VA (HHL / LHL) as a source of feedback affect children's learning?

An analysis of covariance (ANCOVA) was conducted to determine whether there was a significant difference in the effect of the VA persona representation in DGBL on the post-test scores and pre-test achievement scores of the two groups. As shown in Table 1, when the pre-test achievement scores of the first experimental group (DGBL+HHL) were controlled, the mean post-test score was M = 32.50 (SD = 1.46). When the pre-test achievement scores of the second experimental group (DGBL+LHL) were controlled, the mean post-test score was M = 30.00 (SD = 2.35). To test whether this observed difference in the VA persona representation between the two groups' post-test scores was significant, Table 2 presents the results of the ANCOVA.

Table 2 ANCOVA results for children of the two groups related to IAT scores (pre/post).

Source of variance	Sum of squares	*df*	Mean Square	*F*	Significance level (*p*)
Pretest	10.491	1	10.491	2.949	.095
Groups	64.805	1	64.805	18.217	.000
Error	124.509	35	3.557		
Total	37460.000	38			

According to the results of the analysis of covariance (ANCOVA), after controlling for pre-test scores, to determine whether the representation of the VA persona was effective in the mean post-test scores of the two groups. This value turned out to be less than .05. In other words, the VA persona was both influential and effective in terms of the mean post-test scores of the two groups with a statistical significance ($F = 18.21$; $p \geq .05$). There was a significant difference in IAT achievement scores for children who used the DGBL program based on a VA (HHL) compared to children who used the DGBL program represented by a VA (LHL). The difference in the representation of the VA persona in DGBL between the two groups' post-test scores stemmed from the group who used the DGBL program with a highly human-like VA persona representation.

2. To what extent does the representation of VA (HHL / LHL) as a source of feedback affect children's motivation?

Table 3 displays the results of a t-test for two independent groups. This test aimed to determine whether there was a statistically significant effect of the VA persona representation on the children's scores on the MS scale in both groups.

Table 3: Results of the t-test between the two groups related to the motivation scale.

Dependent variable	Independent variable	*N*	*M*	*SD*	*df*	*t*	*p*
MS	**G1: HHL**	20	53.50	2.43	36	4.065	.000
	G2: LHL	18	50.33	3.35			

Looking at the t-test results presented in Table 3, it is clear that there is a significant of the VA persona representation between the MS scores of children who used the DGBL supported by VA (HHL), with M = 53.50 (SD = 2.43). Greater than the mean of the second group that interacted with the DGBL supported by a VA (LHL), with M = 50.33 (SD = 2.35). The differences were significant at a t=4.06 ; P≥.05.

3. To what extent does the representation of the VA (HHL /LHL) as a source of feedback affect children's retention test?

To answer this question, we determined whether there was a significant difference in the effect of the

VA persona representation between the retention test scores of the two groups. Table 1 shows that there was a decrease in the mean scores of the learning retention test for both groups compared to the mean scores of the post-test. The mean retention test score for children who used (DGBL+HHL) was M = 31.35 (SD = 1.66). They performed more successfully than children who used DGBL+LHL was M = 28.49 (SD = 1.21). Table 4 displays the results of a t-test for two independent groups. This test aimed to determine whether there was a statistically significant effect of the VA persona representation on the children's scores on the retention test in both groups.

Table 4: Results of the t-test between the two groups on the retention test.

Dependent variable	Independent variable	*N*	*M*	*SD*	*df*	*t*	*p*
MS	**G1: HHL**	20	31.35	1.66	36	2.918	.006
	G2: LHL	18	28.49	1.21			

Looking at the t-test results presented in Table 4, it is clear that there is a significant of the VA persona representation between the retention test scores of children who used the (DGBL+HHL) VA, with M = 31.35 (SD = 1.66). Greater than the mean of the second group that interacted with the (DGBL+LHL) VA, with M = 28.49 (SD = 1.21). The differences were significant at a t=2.918 ; P≥.05.

4. What is the relationship between motivation and learning of scientific concepts for children in the two study groups (DGBL+ HHL) and (DGBL + LHL)?

Table 5 displays the results of the Pearson correlation coefficient, to test the extent of the relationship between the scores of the post-scientific concepts test and the scores of the motivation scale recorded by the teachers for both groups.

Table 5: The results of the Pearson correlation coefficient.

		Motivation Scale	Post-Test
Motivation	Pearson Correlation	-	.334*
	Sig. (2-tailed)		.040
Post-Test	Pearson Correlation	.334*	
	Sig. (2-tailed)	.040	
*. Correlation is significant at the 0.05 level (2-tailed).			

Considering the Pearson correlation coefficient results shown in Table 5, it is clear that there is a strong, statistically significant positive relationship between the motivation scale scores and the post-test scores of scientific concepts for both groups (HHL/LHL). The Pearson correlation coefficient (r) value was r = .334; P≥ .05.

4.1. Discussion

In this study, both the DGBL+HHL and DGBL+LHL groups showed significant improvement in the post-test compared to their pre-test scores, demonstrating the positive effect of the DGBL program on children's acquisition of SC and enhancing motivation. These findings are consistent with existing research, which highlights the effectiveness of DGBL in learning scientific concepts and motivation by providing an immersive environment that simulates real-world contexts (All et al., 2017; Wu et al., 2025). While empirical evidence supports the role of the DGBL program in enhancing the learning of practical concepts, results also reveal that the DGBL+HHL group achieved significantly greater gains in concept development, retention, and motivation than the DGBL+LHL group. This suggests that incorporating a HHL virtual agent into a DGBL program enhances the benefits of the DGBL program on children's learning and motivation compared to incorporating a LHL virtual agent. The current study found that HHL virtual agent feedback affected learning processes, such as motivation, acquisition, and retention of SC.

First, HHL virtual agent feedback reduced children's confusion, which is consistent with previous studies (Woolf et al., 2010; Lang et al., 2024). In line with social presence theory, our results somewhat demonstrated the beneficial nature of HHL virtual agent feedback in improving children's motivation by enhancing the convergence between the teacher's personal presence and the children. In this study, children who interacted with the DGBL program supported by a VA (HHL) recorded higher engagement on the MS as observed by teachers during the learning phase. Confusion and distraction were expected among children when interacting with a HHL virtual agent compared to a LHL virtual agent. Schneider et al. (2019) noted that younger children experienced increased cognitive load in the high teacher similarity condition and became distracted. In this context, Van Pinxteren et al. (2020) suggested that a LHL virtual agent might be a better learning tool for increasing motivation than a HHL agent for children. However, the feedback the children received from the virtual agent HHL may have primarily served to reduce confusion, contrary to what was expected. This supports the affective response theory (Bhutoria, 2022; Baylor & Kim, 2009) and the cognitive theory of multimedia learning (CTML) (Mayer, 2014), which suggests that increased learning is associated with increased or decreased

cognitive engagement through the activation of emotional and motivational states (Mutlu-Bayraktar, 2024). In addition to the social presence theory, which shows that children will have a more positive experience and enthusiasm for the learning process, when they perceive the presence of the virtual agent HHL (Oh et al., 2018; Anne et al., 2021). In light of this, when children perceived the VA persona HHL, it provided them with a more stimulating experience for the learning process compared to the VA persona LHL.

Second, as expected, children's intrinsic motivation and learning were in favor of the HHL agent with the feedback condition compared to the LHL agent condition. In line with social presence theory and social agency theory, HHL virtual agent behaviors created a supportive atmosphere and reduced communication barriers in human-computer interaction (Lin, et al., 2013, Liew & Tan, 2016A). As a result, children perceived the positive interaction as more intimate, which motivated them to engage in learning (Guo & Goh, 2016), which had a significant impact on learning SC and motivation. This is consistent with the findings of the study by Piumsomboon et al. (2018) who showed that interaction with human-like agents creates significant engagement with users and creates a positive user experience. This explains the existence of a relationship between children's acquisition of SC in both research groups and motivation. This means that there is also a relationship between children's awareness of the presence of the VA in the interaction interface and their increased interaction with DGBL, which was reflected in the increase in their scores on the subsequent test, especially for the (DGBL+HHL) group.

However, contrary to interference theory (Pan & Hamilton, 2018) and cognitive load theory, which suggests that virtual agents' memory resources (HHL) are limited in terms of storage and learning duration (de Jong, 2010), HHL feedback did not negatively affect cognitive load or learning performance. According to previous studies, increasing the direct useful information for cognitive processing of the HHL virtual agent helped children build knowledge compared to the LHL agent (Winn et al., 2019). In this study, the VA's feedback only mimicked the children's motivation and provided emotional support, allowing it to regulate motivational and cognitive factors. This means that HHL feedback did not increase external cognitive load or impede learning. That is, HHL feedback did not engage children's mental resources, nor did it create distractions that would have diverted their attention from the learning content. In addition, this result contradicts the results of studies that indicated that learners experienced high mental loads and performed poorly when learning from a semi-human educational agent (Chang et al., 2022; Florian et al., 2020). The finding also contradicts the uncanny valley theory (Nidhi et al., 2022), which suggests that when a VA closely resembles a human, children may experience uncanny feelings and less emotional excitement (Angela & Robin, 2014).

On the other hand, regarding learning processes, our results supported that feedback from the VA enhanced intrinsic motivation and positive cognitions. The five-stage model of computer-based formative assessment suggests that learners adjust their motivational and cognitive states according to the feedback they receive in a test-like task (Timmers et al., 2015). Hence, children viewed self-assessment as a facilitator of learning, believed they had control over their learning, and engaged in learning tasks (Wang et al., 2019). Feedback to the HHL virtual agent supported cognitive processing and motivational modification compared to the LHL virtual agent. One explanation may be that different attribution styles have opposite effects on emotions and motivation (De Sixte et al., 2019).For example, when children receive feedback from a VA (LHL) to correct a wrong answer, they experience negative emotions because they attribute the failure to the agent's own lack of ability(Arztmann et al., 2022; Gui et al., 2023). Conversely, children interacting with the HHL virtual agent may attribute failure to high difficulty and expect help from it, so they believe that feedback from the HHL virtual agent can help them learn new things better, and thus feel more positive emotions (Alotaibi, 2024; Behnamnia et al., 2023).

On the other hand, according to human-computer interaction studies, learning technology design should integrate both design thinking and learning theories, focusing on the social and contextual aspects of learning environments when introducing new technologies, thus complementing rather than replacing traditional teaching methods (Gause et al., 2022). The novelty effect, which occurs when a new system is introduced to an environment, often leads to increased interest (Koch et al., 2018). Initial curiosity and a desire to understand the system's functionality drive user engagement (Kidd & Hayden, 2015). Feasibility studies and pilot studies (Coelho et al., 2023, 2024) for this research have highlighted that the HHL virtual agent integrated into DGBL has been considered innovative, representing a distinct educational approach for children. Given that the nature of learning in

kindergarten typically takes place in face-to-face classrooms, our preliminary findings suggest that digital elements positively influence children's perceptions of pedagogy. DGBL supported by the HHL agent itself may have an effect on novelty, as it may have enhanced perceived interest, which could explain gains in conceptual learning and motivation (Koch et al., 2018). Thus, the design of the HHL virtual agent in DGBL materials enhanced learning (Christopoulos & Mystakidis, 2023). The HHL virtual agent also added cognitive and emotional dimensions to digital experiences, enhancing the effectiveness of the design (Piumsomboon et al., 2018). Although elements of digital game-based learning may be interesting for research purposes (Govender & Arnedo-Moreno, 2021), the design of the virtual agent must align with pedagogical strategies, preferably through iterative design to identify the most appropriate and maintain engagement beyond novelty, creating efficient and effective learning experiences.

5. CONCLUSION

This study examined the impact of combining two virtual agent characters (HHL/LHL) in a DGBL environment on children's learning and motivation, revealing significant improvements in conceptual understanding and motivation for both groups. From a conceptual understanding perspective, both groups showed improvements on a subsequent science concepts test, but the DGBL+HHL group showed significantly greater conceptual gains, particularly on the posttest. This suggests that feedback from the HHL virtual agent played a crucial role in enhancing children's understanding of scientific concepts and facilitating cognitive organization in DGBL. Regarding motivation, the results indicate that the integration of the HHL virtual agent enhances the DGBL program's ability to raise children's motivation. Significant differences were also observed between the two groups across motivation components, with the DGBL+HHL group showing significantly higher motivational intensity than the DGBL+LHL group. Children in this DGBL+HHL group also demonstrated greater motivational improvement, as observed by teachers during the children's interactions with DGBL. In terms of retaining learning of scientific concepts, children in the DGBL+HHL group demonstrated significantly greater retention than the DGBL+LHL group. The study found a relationship between motivation and preschool children's learning of scientific concepts. The results show that incorporating a VA as a source of feedback into a DGBL program provided a more organized and stable error correction process, higher immersion, and proactive interaction with the HHL agent compared to the LHL agent group. Feedback from the HHL virtual agent facilitated effective cognitive regulation and sustained engagement in learning, contributing to improved children's learning outcomes and enhanced motivation.

This research highlights the ways in which the HHL virtual agent enhances DGBL's functionality for learning scientific concepts and motivation. While DGBL provides an ideal environment for authentic learning, its traditional feedback mechanisms tend to be limited, passive, and simplistic. The incorporation of the HHL virtual agent overcomes these limitations by adopting a teacher-like role, providing guided language adaptation that supports children's cognitive regulation. In traditional DGBL environments, children often rely on trial and error for cognitive exploration. However, with the help of the HHL virtual agent, they can correct errors in real time, follow a more structured error-correction process, and leverage interactions with the HHL virtual agent to monitor and improve their learning progress. Additionally, the HHL virtual agent acts as an interactive conversation partner, enabling discussions about scientific knowledge and other areas of interest within the context of DGBL. This expands the range of children's interactions within the DGBL environment, creating a more comprehensive and engaging learning experience. By providing personalized and timely support, the HHL virtual agent not only enhances the effectiveness of DGBL in promoting concept acquisition and motivation but also fosters positive, process-oriented learning behaviors. This study provides empirical evidence highlighting the role of the HHL virtual agent in enhancing DGBL for children's learning of scientific concepts.

5.1. Limitations and Future Studies

This research has two limitations that should be addressed in future research. First, the experimental period did not exceed 6 weeks, which may not be sufficient to monitor the long-term effects of VAs on SC learning outcomes and motivation. Future studies with longer time periods could provide deeper insights into the sustained impact of virtual agent-enhanced DGBL on children's cognitive and emotional development. Second, the VA(HHL/LHL) in this research was restricted to predefined prompts and responses, which may have limited its ability to fully simulate human-like interactions. Future research and development of VA-enhanced DGBL for science concept learning could focus on

integrating advanced AI functions, such as adaptive support and real-time learning analytics, to unleash the potential of game-based concept learning enhanced by VAs. The effects of VA personality in DGBL were limited to SC learning and motivation. Future studies may explore the effects of VA personality on children's various behavioral patterns.

Data Availability: Data are not publicly available. Please direct data access requests to the corresponding author.

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