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Digital Game-Based Inquiry Learning to Improve Eighth Graders' Inquiry Skills in Biology

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Abstract

This research focuses on *BioScientist*, a digital game-based, inquiry-based learning program embedded in the biology curriculum that develops inquiry skills in 8th-grade students. The aim of this paper is to demonstrate a combination of elements of digital game-based learning (DGBL) with inquiry-based learning (IBL) through *BioScientist* and to report on its implementation. We examined whether inquiry skills and biology learning motivation change due to *BioScientist*. A total of 257 eighth graders participated in the research ($N_{exp.} = 132$, $N_{control} = 125$). Students in the experimental group used *BioScientist* at home and in the classroom. The teachers in the control group did not change their teaching practices. Students' inquiry skills were measured using the Inquiry Skills Test, and their biology learning motivation was measured using the Biology Motivation Questionnaire II. The experimental group and teachers were asked to evaluate *BioScientist*. The results indicated *BioScientist* digital game is suitable for developing inquiry skills, with the effect size being close to medium (Cohen's $d = 0.46$). However, biology learning motivation was not developed. Student feedback on the *BioScientist* game and its use for learning is favourable. Based on the teachers' responses, *BioScientist* can be used well in teaching biology. This research provides evidence that combining elements of digital game-based and inquiry-based learning is effective in developing inquiry skills. The game can be effectively integrated into the teaching practice, in line with the content of the biology curriculum.

Keywords Inquiry skills · Digital game-based learning · Game-based inquiry learning · Biology

Introduction

Nowadays the methods of learning are changing, and these changes highlight the importance of thinking skills, inquiry-based learning (IBL) and STEM (Science, Technology, Engineering, and Mathematics) approaches (Hava & Ünlü, 2021). Therefore, one focus of educational research in recent years is on a combination of three areas: (1) developing 21st-century skills (2) in technology-rich, (3) inquiry learning environments (Chu et al., 2017; Sun et al., 2022).

Students should master the most important key concepts, facts, theories, laws, and models, but also methods and practices of scientific inquiry (Sjøberg, 2019). IBL has become widespread in the development of inquiry skills as recommended by the National Research Council (NRC, 1996). Since the advent of IBL, several innovative methods have emerged in the literature that can be combined with IBL and offer novel learning opportunities (Chu et al., 2017; Liu et al., 2021). In line with this, research on game-based science learning (GBSL) has also become a popular research area (Li & Tsai, 2013; Tsai & Tsai, 2020). One of

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these new trends is the integration of game elements into the research environment (Dziob, 2020; Hsiao et al., 2020). This approach is called game-based, inquiry-based learning, which refers to the cross-section of digital game-based learning (DGBL) and inquiry-based learning, where IBL takes place in a digital game environment (Chen et al., 2020; Srisawasdi & Panjaburee, 2018).

Research indicates that guidelines are needed to help us understand how DGBL can be implemented in science learning. A number of studies have highlighted that suitable learning strategies must be integrated into digital game-based learning to effectively enhance learning achievement and that gameplay design and game mechanisms must be strengthened (Abdul Jabbar & Felicia, 2015; Hsu & Wang, 2018; Wang et al., 2022; Yang & Lu, 2021). Another research problem is that it is not sufficient to know that game-based learning (GBL) and DGBL can support IBL. We need to know how games can support IBL. We need specific guidelines/frameworks to understand how and why it works (Gao et al., 2019).

The purpose of this study is to describe the *BioScientist* digital game development and implementation over six weeks in an eighth-grade classroom, in which game elements support inquiry-based learning embedded in biology subject content. The study was carried out in the context of Hungarian science education. In Hungary, biology is taught as part of the science subject in grades 1–6 and as a separate subject in the following grades of primary school (grades 7–8).

Theoretical Background

Digital Game-Based Learning (DGBL)

DGBL is a learning approach organised around digital games, a form of student-centred learning in which educational goals are assigned to digital games (Tan et al., 2008). To understand digital games, it is worth returning to the definition of game by Salen and Zimmerman (2003), who see the game as a system. The digital game is also a system, an important element of which is the digital platform. At the same time, digital games can refer to different digital technologies, since digitality can be considered as an element of the system. Based on this, the characteristics of digital games are (1) immediate but narrow interactivity, (2) manipulation of information, (3) automated complex systems, and (4) networked communication. Digital games are rule-based, formal systems that have variable and quantifiable outcomes, where different learning outcomes have different values, and where the player makes an effort to influence learning outcomes (Juul, 2003).

According to Prensky (2001), play in DGBL is a type of entertainment that requires intense and passionate participation, in addition to being interactive and adaptive. The game has rules, as well as a goal and result that motivate the student. Conflict, competition, challenge, and problem-solving play a part in the game. Furthermore, games have representations and stories that affect emotions. Therefore, the advantages of digital games are that they form an active and engaging environment to support problem-solving, communication, and group activities and learning. Furthermore, they create safe spaces where students can play, experiment, explore, and enjoy themselves (Whitton, 2012).

Digital games can be classified into the following groups: (1) special-purpose digital games, (2) commercial off-the-shelf games (COTS), and (3) digital game co-creation (Stewart et al., 2013). Of those listed, commercial games are less suited to achieving learning goals, since their primary purpose is entertainment. In the case of digital game development, learning and participation are achieved through the creation and design of these games.

The use of special-purpose digital games was preferred during education. Based on the planned primary learning outcome, we distinguish between three types of special-purpose digital games: (1) knowledge transfer, (2) skill development, and (3) attitude change. DGBL is primarily aimed at achieving a certain type of learning outcome, but these goals are not exclusive. Thus, a digital game whose primary goal is to improve students' cognitive learning outcomes can also lead to a change in attitude as a secondary learning outcome (Stewart et al., 2013).

Although the development and use of various game concepts in digital learning environments are very popular, the development of digital games is still not fully established (Schöbel et al., 2021). Recent research has also drawn attention to the fact that different game mechanisms have different effects, which is why the design of games is crucial (Clark et al., 2016). Critical and contextual information on learning-game integration or game design features is needed and researchers should endorse more rigorous research design in conducting value-added comparisons with game design and implementation features (Pan et al., 2022). Learning games are increasingly seen as a planned pedagogical tool for classroom instruction, rather than as a separate teaching–learning opportunity (Ke, 2016). Therefore, educational aspects such as the relationship between the learning objective, the subject content, and the type of game are increasingly important in the design of learning games. Game designers need to pay attention to designing games as pedagogical instruments, adapting game activities to learners' preferred play modes, and ensuring learners' prior knowledge and learning tasks. Game content should be in line with the curriculum and requirements. This can help teachers to select and integrate into classroom teaching the games that best suit the learning objectives and subject content (Pan et al., 2022).

Integrating the Development of Inquiry Skills into Science Teaching

From a pedagogical perspective, scientific inquiry can be interpreted in three ways: as a set of skills, as a cognitive output, and as an inquiry-oriented teaching approach (Özlegen, 2012). Inquiry skills – which according to Wenning (2007) include: identifying the problem to be researched; formulating hypothesis; planning the experiment to test the hypothesis, conducting a scientific experiment; collecting, systematizing, and accurately analysing the data; and applying calculations and statistical methods – are closely related to critical thinking and problem-solving (Bao et al., 2009).

How to integrate the application of inquiry skills into science teaching has long been a concern for researchers. As early as 1996, the NRC (1996) developed ideas for teachers to teach science with learner-centred, active learning methods and activities. The National Research Council (NRC) (2000) stresses that teachers should design inquiry-based programs, guide and facilitate the learning process, continuously evaluate their teaching and children's learning, and design and manage learning environments that provide time, space, and resources to teach science. In addition, they should develop communities of science learners that reflect the intellectual rigour of scientific inquiry as well as attitudes and societal values conducive to science learning.

There are many ways to develop inquiry skills (e.g. Fan & Ye, 2022; Harlen, 2014; Lee et al., 2010; Martin-Hansen, 2002). One widely used method is inquiry-based learning, which is distinguished into four types: (1) confirmatory, (2) structured, (3) guided, and (4) open (Banchi & Bell, 2008). The taxonomy is based on whether the results are known and the extent to which the teachers help the research process. Although open IBL best reflects the work of scientists (Banchi & Bell, 2008), at the same time, this type of research is fraught with difficulties. Furthermore, the inquiry processes can be time-consuming, be it laboratory or field work, an excursion, or a discussion (Sjøberg, 2019). Lazonder and Harmsen (2016) in their meta-analysis highlighted that IBL is effective when it is supplemented with guidance. The application of IBL requires a variety of knowledge and skills from both teachers and students. Therefore, appropriate teacher support and student scaffolding are extremely important (Lehtinen & Viiri, 2017).

Inquiry skills develop gradually in the context of practice in activities (Dean & Kuhn, 2007). Therefore, they should not be developed at a particular point in the training but should be continuously integrated into the process of science learning (Kuhn & Pease, 2008).

Game-Based Inquiry Learning

Since the 2000s, educational researchers have argued that games and combinations of different methods have significant benefits for science education (Cheng et al., 2015; Chu et al., 2017; Clark & Martinez-Garza, 2012; Li & Tsai, 2013; Nkadimeng & Ankiewicz, 2022; Tsai & Tsai, 2020). A number of studies have highlighted the potential of games to support IBL (Chen et al., 2020; Dorji et al., 2015; Gao et al., 2019; Tsai, 2018). Game-based inquiry learning is an innovative, technology-enhanced approach that incorporates the benefits of both DGBL and IBL. In this case, game elements are built into the research environment and the scientific content is transformed into a game strategy; game-based IBL is therefore a process-oriented, inquiry-based, active learning approach (Srisawasdi & Panjaburee, 2018).

The games related to inquiry-based learning that appear in the literature are diverse (Gao et al., 2019). For example, the *River City* (Ketelhut, 2007) is a multi-user virtual environment (MUVE), which enables the student to engage in scientific research in teams of 2–4 members. The results highlighted that MUVE can act as a catalyst for changing students' self-efficacy and learning processes. The *Quest Atlantis* (Barab et al., 2005) applies MUVE, and the emphasis is placed on engaging classroom culture and relevant aspects of student life to encourage engagement with social engagement and educational goals interpreted locally. Hwang et al. (2015) developed a contextual educational computer game to situate students in inquiry contexts for social studies courses. The contextual computer game enhanced students' learning achievement, learning motivation, degree of satisfaction, and flow state. Wen et al. (2020) suggested an interactive simulation with embedded inquiry support. Tsai et al. (2019) proposed a GAME (Gamification, Assessment, Modelling, Enquiry) model which can enhance students' scientific competencies. Dorji et al. (2015) developed the *Residence Energy Saving Battle* (RES battle) game, which contains five interfaces and four databases. The game supports exploration in the game, discussion, and knowledge construction. Their results highlight the importance of interactions both on the game screen and with other students in reducing the gap between female and male learning outcomes. Nietfeld (2020) has integrated the *Crystal Island: Uncharted Discovery* game into classroom instruction in Grade 5 and, based on a self-regulated learning approach. The *Science Detective Squad* (Tsai, 2018) is a computer-simulated science inquiry environment, which significantly increased students' electrical knowledge, and the majority of students expressed positive perceptions about the inquiry environment.

In a systematic review, Gao et al. (2019) analysed eleven studies that presented research on games to support inquiry-based learning. The analysis revealed several game elements that support IBL in various ways (the hierarchical structure of learning processes, meaningful environment, and guidance). Only seven of the studies analysed measured the impact on learners, and all showed significant improvements in learners' knowledge and information-seeking strategies. However, the evidence for learner engagement and motivation is not clear (Ryan & Rigby, 2020; Wouters et al., 2013). This suggests that further research is needed to investigate the educational impact of games that support inquiry-based learning.

From the point of view of instruction, in this case, biology teaching, it is an important issue how the linking of DGBL and IBL can be brought in line with the curricular learning objectives, the content of the subject, and how it can be embedded in the teaching and learning process.

Current Study

Our research aimed to design and implement a digital game that can be embedded in the learning process. The educational objectives of the game were to help students acquire the skills needed for scientific inquiry while supporting their motivation to learn biology. The following research questions are addressed:

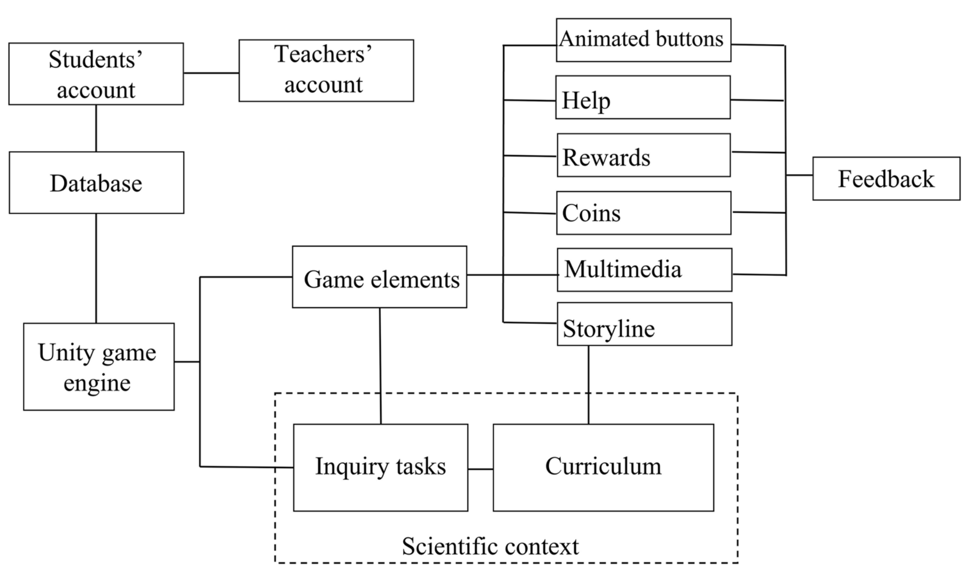
1. Is there a difference in inquiry skills between the students involved in the intervention and those in the control group?
2. Is there a difference in motivation towards biology between the students involved in the intervention and those in the control group?
3. Is there a gender difference after the intervention in terms of inquiry skills and biology learning motivation?
4. How do the students evaluate the *BioScientist* digital game?
5. How do the teachers evaluate the *BioScientist* digital game?

Designing the BioScientist Digital Game

BioScientist is a single-player, 2D computer game designed for 8th graders to develop inquiry skills based on the content of the biology curriculum, combining elements of digital game-based and inquiry-based learning. The program was written with the Unity game engine (version 2019.2.19f1) using the C# programming language. Figure 1 shows the *BioScientist* digital game design.

The game allows for individual learning, which can be combined with teacher-led class discussions. Both students and teachers can register on the *BioScientist* webpage, and they can create their own accounts. After registering, users can access their accounts on the login interface. The teacher's account contains a teacher function that allows the teacher to monitor student activity in the digital game. This is based on the fact that every step of the students is logged in the database. Students can move forward in the digital game in a linear way, while the teacher can choose different stations. The reason for this is that, to develop inquiry skills, the students have to complete all the tasks, while it is practical for the teachers to be able to choose between the scenes during classroom discussions and not have to complete all the tasks to move from one scene to the next. This also provides them the opportunity to return to each scene several times during the class discussion and to select the tasks that the students found difficult.

Fig. 1 *BioScientist* game design



IBL-supporting Functions of Bioscientist Game Features

The game elements that support inquiry-based learning in *BioScientist* are presented in Table 1, based on the system developed by Gao et al. (2019). The storyline, the content of the *information* icon, and the smaller units (stations) ensure that the students acquire scientific knowledge and understand the process and methods of scientific inquiry better.

The storyline involves three generations of a particular family. Each station focuses on one family member, with the whole family being presented at the beginning of the program. As for stories related to family members, we made sure that they were ordinary, so that events, problems, and diseases were presented that the students would also know from their own family environment. For example, they need to choose the appropriate insulin for the grandmother, as she is diabetic; grandpa goes to the family doctor with a kidney complaint and orders various tests; and finally, grandpa is diagnosed with kidney stones.

The IBL process is divided into stations, with one station consisting of three to eight tasks. When compiling the stations and tasks, we followed the principle of gradation, so the students are always given easier tasks first and then gradually more difficult tasks. On some tasks, the students are expected to use one inquiry skill (e.g. interpretation of data), but there are also more complex tasks that follow the steps of structured IBL. The storyline is connected to real problems and questions; thus, students can engage in completing the tasks.

We placed the permanent elements in the upper right-hand corner of the canvas (the *satchel*, *speaker*, *backpack*, and *information* icons). Coins for completing tasks are collected in the *satchel*. Students can turn the background music on and off with the *speaker*. The students collect the rewards they received while completing the tasks in the *backpack*. The information icon contains additional points of interest or information necessary to do the task.

By clicking on the *information* icon, the learner can read about the research methodology or biological supplementary information related to the task, such as the concepts of dependent and independent variables and controlled variables in the context of designing experiments. In another task, the student can read about what the sunscreen factor number means.

The students receive coins and rewards for completing the tasks (a vital capacity meter, BMI key, magic microscope, and urine test strip). Rewards are required for further progress between stations or within a station. In exchange for the coins, the students can buy help to complete the tasks. The *help* canvas does not provide the solution, but contains instructions and questions that provide scaffolding as the student completes the task. Simpler tasks are accompanied by one *help* canvas, but more difficult tasks have up to three canvases. At the same time, it is not necessary to use all the help because it is possible for the student to complete the task after being helped once. This type of feedback makes self-regulated learning possible.

Table 1 IBL-supporting game features (based on Gao et al., 2019)

Game features	*Support provided for core IBL characteristics*		
	Guidance	*IBL structure*	*Meaningful environment*
Game tips	The *information* icon contains supplementary information		
Scoring system	Coins and rewards reflect activities being done correctly		
Storyline	The storyline guides the progression of the game: family members come into focus consecutively	The storyline provides a specific structure for the inquiry processes: problems related to the health of family members	The storyline ensures background information
Structured game tasks	Progressively more difficult tasks: increasingly complex operations and handling more variables	Structuring game tasks according to the inquiry-based learning phases	Game tasks are related to real phenomena
Contextualised feedback	The *help* canvas with instructions and questions		It lends meaning to actions and results, supports self-regulated learning
Gameplay-context coherence			It provides a link between the curriculum and everyday life, helping students to understand the relevance of biological knowledge and scientific inquiry

Table 2 Content of the *BioScientist* digital game

Inquiry skills	Topic	Number of tasks	
Design experiment	Digestion	1	9
	Breathing and health	1	
	Excretion	1	
	Digestion	6	
Identification and control of variables	Pulse change	4	11
	Breathing and health	1	
	Breathing and health	4	
	Excretion	2	
Interpretation of data	Skin	1	12
	BMI	3	
	Breathing and health	1	
	Blood donation	1	
	Diabetes	5	
	Excretion	1	
Conclusion	Skin	1	9
	Digestion	2	
	Breathing and health	2	
	Blood donation	1	
	Diabetes	3	

In addition to collecting coins and rewards, the students are motivated by sound effects, animated buttons, interactive interfaces, and 2D animated game elements placed between the stations. The animated buttons, help canvas, coins, rewards, and sound effects provide feedback for the students.

Structure and Content

The game involves nine stations with 3–8 tasks per station. The focus of the tasks is on inquiry skills, but the content was also an important aspect during the design process. The content of the tasks follows the 8th-grade Hungarian biology curriculum and covers the following topics related to the skin, the musculoskeletal system, body metabolism, regulation of life processes, and perception: the layers of the skin, the factor number of sunscreens, receptors in the skin, pulse, resting pulse, pulse changes due to movement, the role of glandular secretions (saliva, gastric juices, bile, gastric saliva, and intestinal juices) in digestion, the concept and calculation of BMI, vital capacity, blood types, blood typing, kidney function, kidney stones, insulin effect, and diabetes (Table 2).

In general, the knowledge learned in biology lessons is sufficient to complete the tasks. If the task requires specific subject content knowledge in biology, this can be accessed by clicking on the information icon.

From a technical point of view, three different types of tasks were used: simulation, multiple-choice questions (Fig. 2 shows that the student can generate data by combining the values of variables and then answer the question after analysing the data), and drag and drop tasks (Fig. 3 illustrates a blood typing task, where the student produces the data and then analyses them).

The simulation presented in Fig. 2 aims to develop the skill of controlling variables, which is achieved by giving students

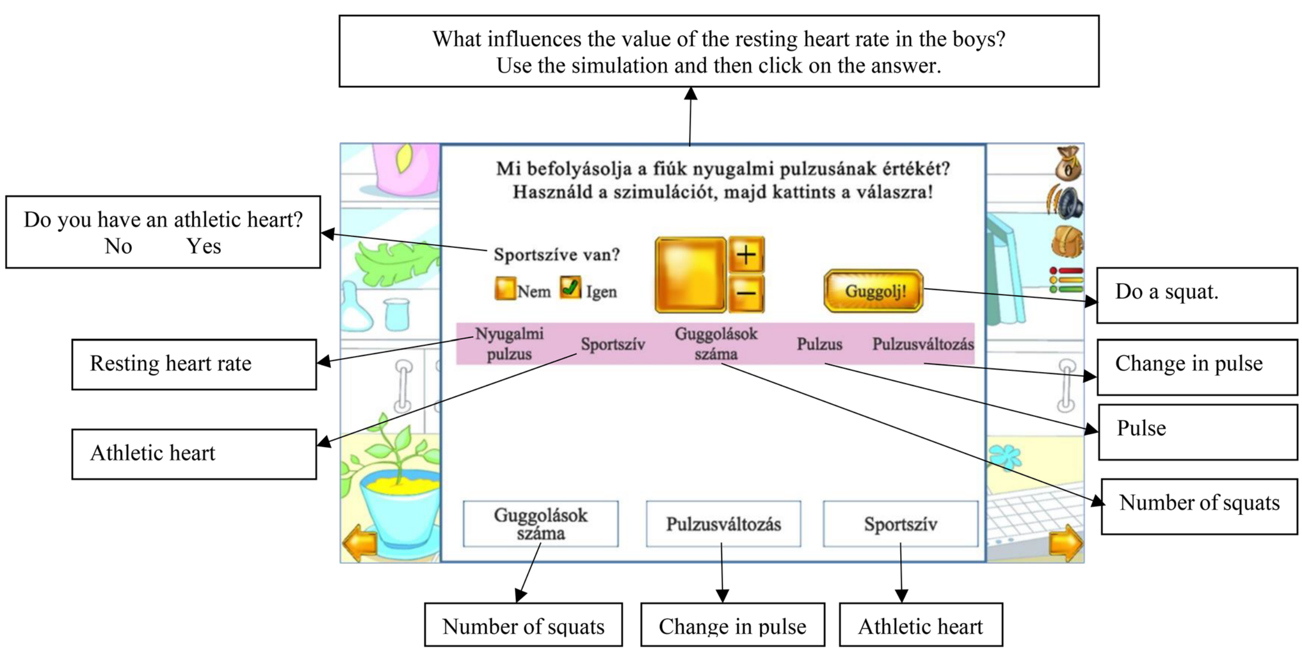


Fig. 2 Example screenshot from the *BioScientist* digital game: relationship between movement and pulse task

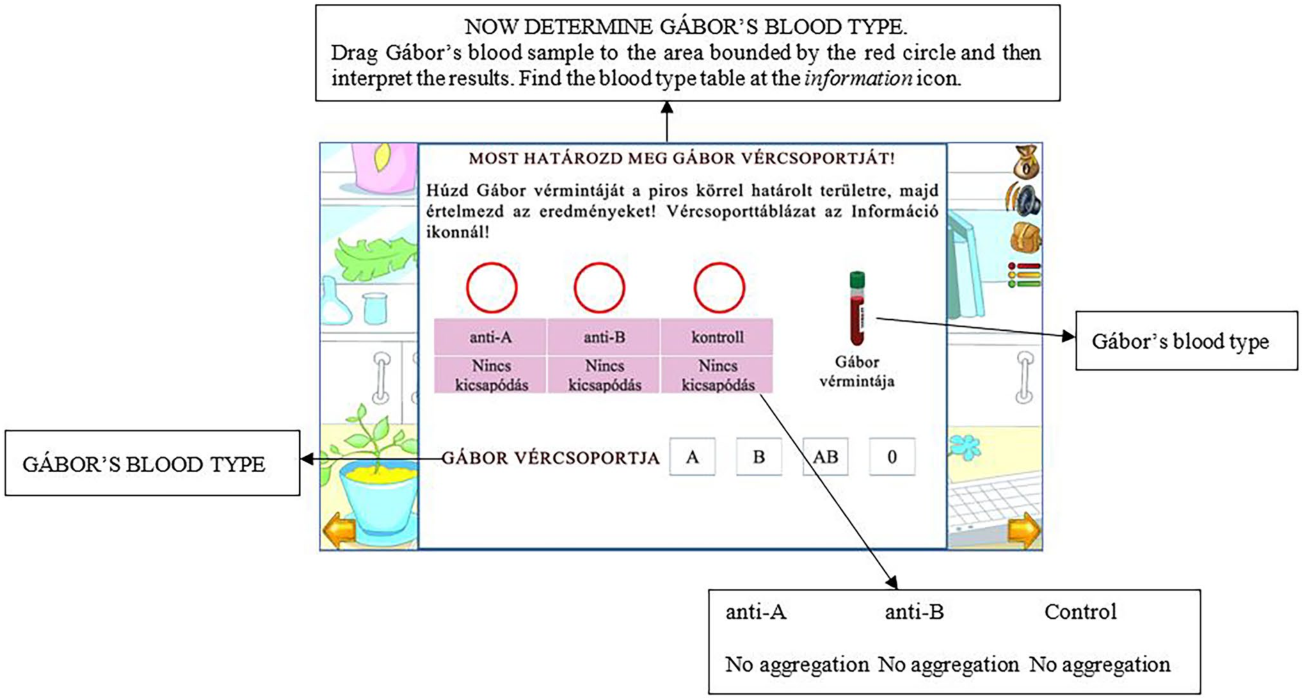


Fig. 3 Example screenshot from the *BioScientist* digital game: AB0 blood typing task

a progressively more difficult task. Using the simulation, they have to manipulate the first one and then two variables. In the most complex task, to answer a question, students are asked to create their own settings and then, based on the data they receive, choose the answer they think is correct (see screenshot in Fig. 2). The simulation, therefore, allows them to make and evaluate a wide range of settings. The task in Fig. 3 asks students to carry out the blood type test, then interpret the data according to the blood type table and draw conclusions.

Methods

The impact of the *BioScientist* digital game was examined in the autumn of 2021 in a quasi-experimental study with an experimental and control group, pre- and post-test design (Table 3). The experimental group used the *BioScientist* game for six weeks and progressed with the curriculum. The teachers in the control group did not change their teaching practices. Gameplay was not used, and the learning material

Table 3 Overview of the experimental design

Week	Student activities			Teacher activities		
	Experimental group		Control group	Experimental group		Control group
Pre-test, preparation	Inquiry Skills Test (IST), Biology Motivation Questionnaire II (BMQ II)			Participation in the preparatory meeting Registration on the BioScientist website		-
	Registration on the BioScientist website		-			
1	*BioScientist* combined with traditional learning	Stations 1–2	Traditional learning	*BioScientist* combined with traditional teaching	Facilitating classroom discussion 1 (Stations 1–3)	Traditional teaching
2		Station 3				
3		Stations 4–5			Facilitating classroom discussion 2 (Stations 4–6)	
4		Station 6				
5		Stations 7–8			Facilitating classroom discussion 3 (Stations 7–9)	
6		Station 9				
Post-test, evaluation	Inquiry Skills Test (IST), Biology Motivation Questionnaire II (BMQ II)			Program Evaluation for Teachers		-
	Program Evaluation for Students		-			

was covered in the usual way. Both groups followed the same curriculum. They learned the same content and processed the tasks offered by the textbook.

The students in the experimental group mainly used *BioScientist* at home, but they also engaged with it in three biology lessons. At the same time, we used a combined method, during which the students used the program both at home and in class. The classroom discussion was important to follow up and reinforce the students' work, as the digital game and the types of tasks it involved were new to them. Checking and discussing the tasks also helped the students to better understand the scientific concepts (e.g. variables) and methods (e.g. experimental set-up) involved in the research process. Three 45-min classroom sessions were included in the schedule, following each of the three stations completed at home.

Before starting the experiment, the teachers in the experimental group attended a training session to learn about the aims of the development, the theoretical and practical aspects of digital game-based research, and the features, design, and use of the *BioScientist* game. They received a guide, which contains the purpose of the program, a general presentation, the task structure, the schedule, and the tasks in the program, complete with solutions and explanations, and they were able to ask questions about the game and its integration into classroom biology teaching. All the teachers received the same instructions on holding class discussions. We asked the teachers to monitor the students' individual work in the game and ask the students about the tasks they had completed during the three classroom discussions. They asked how they evaluated their work and what was easy or difficult for them. It is important to note that the students could not return to the tasks they had already completed and, where necessary, teachers explained the supplementary information that was shown in the information icon but did not provide any new information not otherwise included in the game.

Participants

A total of 257 eighth-grade students from five Hungarian primary schools participated in the study. The mean age was 13.71 years ($SD = 0.50$). The experimental group consisted of 132 students (boys: 68; girls: 64), and the control group had 125 students (boys: 66; girls: 59). The experimental and control classes were from the same schools. Five teachers took part in the experiment. All of them are the students' biology teachers. The same five teachers taught in the control and experimental classes. A total of six experimental and six control classes were involved, with a balanced ratio of boys and girls. The students had not previously used games in learning biology.

Instruments

Online tools were used for both the pre- and post-test. The data were collected in a classroom setting via the eDia system (Csapó & Molnár, 2019).

Inquiry Skills Test

We used the Inquiry Skills Test (Korom et al., 2016) to measure the students' inquiry skills. The instrument contains 15 tasks, 39 items, and aims to assess inquiry skills (identification of research question, hypothesis, identification of variables, design experiment, control of variables, interpretation of data, and drawing conclusions) using everyday or scientific content. The test consists of closed, multiple-choice tasks, and some tasks require the design of experiments with a manipulative combination of given elements (Fig. 4). The reliability coefficients (Cronbach's alpha) were 0.84 and 0.87, respectively, for the pre- and post-tests.

Biology Motivation Questionnaire II

The Science Motivation Questionnaire II (SMQ II) (Glynn et al., 2011) was adapted to Hungarian education, and we used the biology-specific version of the questionnaire by Németh et al. (2022). The Biology Motivation Questionnaire II (BMQ II) contains five subscales: (1) intrinsic motivation, (2) self-efficacy, (3) self-determination, (4) grade motivation, and (5) career motivation. Each subscale has five items. Students are asked to indicate how true each statement is for them in terms of learning biology on a five-point Likert scale (0 = never, 1 = rarely, 2 = sometimes, 3 = often, 4 = always) (Table 4).

The questionnaire measured reliably, with good reliability values for each subscale for both pre-test (0.96) and post-test (0.96).

Program Evaluation for Students

The students in the experimental group completed a program evaluation questionnaire at the follow-up, expressing the degree of agreement on a four-point scale (1 = not at all, 2 = rather not, 3 = rather yes, 4 = completely). We asked students a total of ten questions about using the *BioScientist* digital game in their learning. For example, How much did you enjoy the game? How much did you like the tasks?

Program Evaluation for Teachers

At the end of the experiment, we asked the teachers to evaluate the usefulness of the teacher's guide and the implementation of the *BioScientist* digital game. The questions asked were rated on a scale of 1 to 4, where the scale was 1 = not

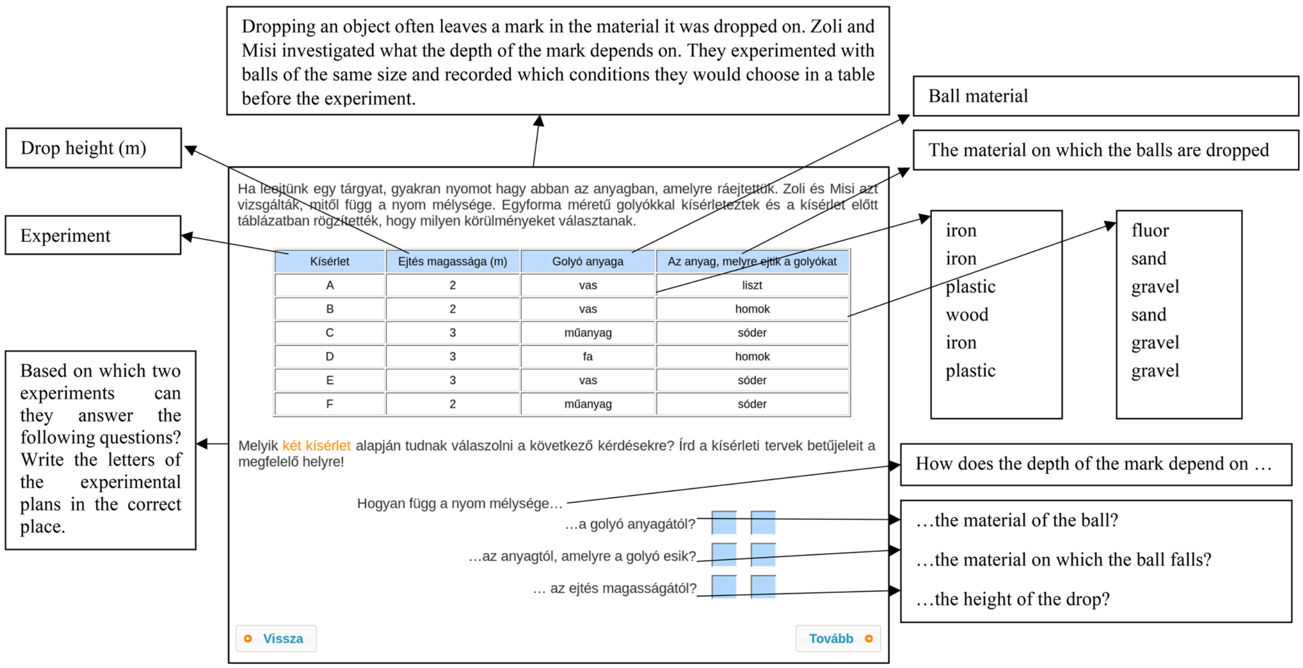


Fig. 4 Example from the Inquiry Skills Test: control of variables task (Korom et al., 2016)

at all, 2 = rather not, 3 = rather yes, and 4 = completely. We also formulated some open questions, which focused on their experience with the program. For example, To what extent were you able to implement discussion of the tasks in your biology lessons? In your opinion, how well does the development program integrate into the 8th-grade biology curriculum?

Data Analysis Procedure

All data analyses were performed using IBM SPSS Statistics 25. To answer the research questions, we used the tools of descriptive statistics (mean, standard deviation) and Pearson correlation for multivariate analyses. The impact of the development program was assessed using paired and independent *t*-tests and by calculating unbiased Cohen's coefficient. A two-way ANOVA was performed to evaluate the effects of experimental design and gender.

Results

Is There a Difference in Inquiry Skills Between the Students Involved in the Intervention and Those in the Control Group?

In the case of the pre-test, there was no significant difference between the experimental and control groups.

Table 4 The Biology Motivation Questionnaire II subscales, descriptions, and example items (based on Glynn et al., 2011)

BMQ II subscale	*Number of items*	*Description*	*Example item*
Intrinsic motivation	5	An internal force that motivates students to participate in learning activities because they are interested in learning and enjoy the learning process (Schiefele, 1991).	Learning biology is interesting.
Self-efficacy	5	Students' beliefs about their own abilities to learn and perform tasks at specific levels (Bandura, 1997).	I am sure I can understand biology.
Self-determination	5	The ability of learners to choose and control what and how they want to learn (Reeve et al., 2003).	I put enough effort into learning biology.
Grade motivation	5	The student studies because of the expectation of external compensation in the form of good grades (Black & Deci, 2000).	I like to do better than other students on biology tests.
Career motivation	5	The student studies because he or she considers science to be valuable for future career opportunities (Black & Deci, 2000).	My career will involve biology.

Table 5 The scores for the experimental and control groups on the Inquiry Skills Test on the pre- and post-tests

Inquiry Skills Test	*Statistical indicators*	*Experimental group N = 132*	*Control group N = 125*	*F-test*		*t-test*	
				F	*p*	|*t*|	*p*
Pre-test	Mean	24.5	25.5	3.31	0.070	1.28	0.201
	SD	6.9	5.9				
Post-test	Mean	28.3	26.9	0.78	0.377	2.01	< 0.05
	SD	6.6	7.2				

As a result of the improvement, the experimental group performed significantly better on the Inquiry Skills Test ($t(255) = 2.01$; $p < 0.05$) (Table 5). The experimental group performed significantly better on the post-test than on the pre-test ($t(131) = 5.56$; $p < 0.001$), while the control group showed no significant improvement compared to itself.

To estimate the effect of *BioScientist*, we calculated effect size (Cohen's d value). In our experimental design (pretest–posttest-control), based on Morris (2008), the unbiased effect size of the program is $d = 0.46$. According to Cohen (1969), a value of $d = 0.8$ is large, a value of $d = 0.5$ is medium, and a value of $d = 0.2$ is an indicator of a small effect size. Therefore, the effect size of the *BioScientist* digital game is nearly medium.

Is There a Difference in Motivation Towards Biology Between the Students Involved in the Intervention and Those in the Control Group?

On the pre-test, there was no significant difference between the control and experimental groups in terms of biology learning motivation. There were no significant changes in any of the motivational components for either group during the development period (Table 6).

Is There a Gender Difference After the Intervention in Terms of Inquiry Skills and Biology Learning Motivation?

In the case of inquiry skills, the experimental and control groups did not show significant gender differences on the pre-test. At the same time, on the post-test, the boys in the experimental group performed significantly better on the Inquiry Skills Test than the girls ($M_{boys} = 29.5$, $SD = 6.2$; $M_{girls} = 26.8$, $SD = 6.7$; $t(130) = 2.36$; $p < 0.05$). In contrast, in the control group, the girls scored significantly higher than the boys on the post-test ($M_{girls} = 28.2$, $SD = 5.7$; $M_{boys} = 25.1$, $SD = 8.2$; $t(123) = 2.45$; $p < 0.05$). Further analysis of gender differences indicates that there was no significant difference on the inquiry skills pre-test between the boys in the experimental group ($M_{exp.} = 23.5$; $SD = 7.0$) and those in the control group ($M_{control} = 24.7$; $SD = 6.0$). However, on the inquiry skills post-test, the boys in the experimental group ($M_{exp.} = 29.5$; $SD = 6.2$) performed significantly better ($t(132) = 3.5$; $p < 0.001$) than those in the control group ($M_{control} = 25.1$; $SD = 8.2$). In the case of the girls, there was no significant difference between the experimental and the control group either on the pre-test ($M_{exp.} = 25.4$; $SD = 6.7$; $M_{control} = 26.3$, $SD = 5.7$) or the post-test ($M_{exp.} = 26.8$; $SD = 6.7$; $M_{control} = 28.2$, $SD = 5.7$).

Table 6 Pre- and post-test scores for the experimental and control groups on the Biology Motivation Questionnaire II by subscale

BMQ II subscale	*Statistical indicator*	*Experimental group (N = 132)*				*Control group (N = 125)*			
		Pre-test	*Post-test*	|*t*|	*p*	*Pre-test*	*Post-test*	|*t*|	*p*
Intrinsic motivation	Mean	13.7	13.0	0.71	0.480	13.8	13.6	0.35	0.730
	SD	4.0	4.4			4.2	4.2		
Self-efficacy	Mean	11.9	11.4	1.56	0.122	11.8	12.0	0.12	0.906
	SD	4.6	4.6			4.5	4.3		
Self-determination	Mean	11.7	11.1	1.05	0.298	11.4	11.7	0.51	0.610
	SD	4.7	5.1			4.5	4.5		
Grade motivation	Mean	13.6	13.1	0.81	0.421	13.8	13.4	0.83	0.408
	SD	4.1	4.9			4.2	4.2		
Career motivation	Mean	12.2	11.8	0.57	0.569	12.4	12.3	0.33	0.740
	SD	4.4	4.9			4.4	4.4		
Total	Mean	63.2	60.7	0.85	0.399	64.0	63.2	0.23	0.822
	SD	19.5	22.1			20.0	20.6		

Scoring 0–4, maximum score 20 on the subscale, 100 on the full instrument

A two-way ANOVA was performed to evaluate the effects of experimental design and gender on the increase in test scores on the Inquiry Skills Test (a variable formed by the difference between pre- and post-test scores). The results indicated a significant main effect for experimental design, $F(1, 242) = 7.986$), $p = 0.005$, partial $\eta^2 = 0.032$; a no significant main effect for gender, $F(1, 242) = 2.717$, $p = 0.101$, partial $\eta^2 = 0.011$; and a significant interaction between experimental design and gender, $F(1, 242) = 10.732$, $p = 0.001$, partial $\eta^2 = 0.042$.

Looking at changes in biology learning motivation, the results of the two-way ANOVA showed that there was no significant main effect of either experimental design, $F(1, 236) = 0.381$), $p = 0.538$, partial $\eta^2 = 0.002$; nor gender, $F(1, 236) = 1.742$, $p = 0.188$, partial $\eta^2 = 0.007$; nor the interaction between experimental design and gender, $F(1, 236) = 0.782$, $p = 0.377$, partial $\eta^2 = 0.003$.

How Do the Students Evaluate the BioScientist Digital Game?

Based on the responses to the Program Evaluation for Students' questions, use of the *BioScientist* digital game was generally judged positively by the students; for all the questions, the most common answer was "3 = rather yes" (Table 7). More than half of the students thought that the game helped them to learn and understand the process of scientific investigation, and they also found the class discussion useful. The majority of the students liked the interesting elements related to the curriculum and would like to learn other topics using *BioScientist*.

In order to get a more detailed picture of the student's opinions, we investigated whether there is a difference in the results of the inquiry skills post-test based on whether the student prefers no (the answer is a value of 1 or 2) or more yes (the answer is a value of 3 or 4) answered the program evaluation questions (Table 8). The independent *t*-test revealed significant differences for the five questions of the program evaluation. Thus, students who performed better on the post-test of inquiry skills enjoyed learning with the *BioScientist* digital game more and would like to learn other topics in this way. They found that the digital game helped them to acquire biological knowledge and to learn and understand the process of scientific research.

Analysing students' responses by gender, the results indicate that the girls preferred using the *BioScientist* ($M_{girls} = 2.7$, $SD = 0.6$; $M_{boys} = 2.2$, $SD = 0.9$, $t(130) = 3.26$, $p < 0.05$) and agreed more that understanding the tasks was facilitated by working together in the lessons ($M_{girls} = 2.7$, $SD = 0.7$; $M_{boys} = 2.3$, $SD = 0.9$, $t(130) = 2.74$, $p < 0.05$). Furthermore, the girls liked the additional interesting topic-related elements more ($M_{girls} = 2.9$, $SD = 0.6$; $M_{boys} = 2.5$, $SD = 1.0$, $t(130) = 2.83$, $p < 0.05$), and they judged the level of knowledge acquired from the program to be significantly better ($M_{girls} = 2.8$, $SD = 0.7$; $M_{boys} = 2.5$, $SD = 0.9$, $t(130) = 2.0$, $p < 0.05$) than the boys.

To better understand the relationship between students' perceptions and other variables, Pearson correlation analysis was carried out based on the results of the experimental group. A program evaluation variable was created which is the sum of the values given by the students for each program evaluation question. The following variables were included in the analysis: performance on the Inquiry Skills post-test, attitude towards biology learning (BMQ II total score; total scores of BMQ II dimensions: intrinsic motivation, self-efficacy, self-determination, grade motivation, career motivation) and biology grade at the end of the previous school year. The program evaluation variable showed a significant positive correlation with the inquiry skills test ($r = 0.28$), BMQ II total score ($r = 0.22$), intrinsic motivation ($r = 0.21$), self-efficacy ($r = 0.21$), and grade motivation ($r = 0.27$) variables (Table 9).

Table 7 Results of the *Program Evaluation for Students* (N = 132)

Program Evaluation for Students' question	*Frequency (%)*				*Mean*	*SD*
	1	*2*	*3*	*4*		
1. How much did you enjoy the *BioScientist* digital game?	17.0	26.8	51.8	4.5	2.4	0.8
2. How much did you like the tasks?	13.4	35.7	45.5	5.5	2.4	0.8
3. To what extent were you able to study independently with *BioScientist* at home?	17.9	28.6	46.4	7.1	2.4	0.9
4. To what extent did working together in class help you understand the tasks?	14.4	27.9	49.6	8.1	2.5	0.9
5. To what extent did the tasks help you understand the biology topics?	15.3	29.7	46.0	9.0	2.5	0.9
6. How much did you like the additional points of interest related to the topics (e.g. athletic heart, factor number of sunscreens, blood donation rules, and the effect of insulins)?	12.6	22.5	53.1	11.7	2.6	0.9
7. To what extent did you manage to acquire the knowledge involved in the game?	10.7	25.9	51.8	11.6	2.7	0.8
8. To what extent did the tasks help you learn and understand the process of scientific research?	16.1	25.0	50.9	8.0	2.5	0.9
9. How much would you like to study other topics with *BioScientist*?	12.6	31.5	40.5	15.3	2.6	0.9

1 = not at all, 2 = rather not, 3 = rather yes, 4 = completely

Table 8 The post-test scores on Inquiry Skills Test based on the program evaluation

Program evaluation's question	*Frequency of responses (%) N = 132*		*Statistical indicators*	*Inquiry Skills Test*		*F-test*		*t-test*	
	Rather negative	*Rather positive*		*Rather negative*	*Rather positive*	*F*	*p*	|*t*|	*p*
1	43.8	56.2	Mean	26.85	30.46	2.59	0.110	2.96	0.004
			SD	7.12	5.56				
2	49.1	50.9	Mean	26.40	31.20	0.40	0.529	4.10	0.000
			SD	6.57	5.58				
3	46.4	53.6	Mean	27.90	29.71	0.39	0.535	1.45	0.150
			SD	6.72	6.26				
4	42.3	57.7	Mean	27.83	29.69	1.72	0.193	1.47	0.146
			SD	5.96	6.89				
5	45.0	55.0	Mean	28.23	29.27	0.14	0.714	0.82	0.417
			SD	6.18	6.74				
6	35.1	64.9	Mean	27.18	29.71	0.69	0.410	1.95	0.054
			SD	6.83	6.16				
7	36.6	63.4	Mean	26.00	30.46	0.10	0.757	3.58	0.001
			SD	6.09	6.22				
8	41.1	58.9	Mean	27.02	30.08	0.41	0.525	2.43	0.017
			SD	6.14	6.50				
9	44.1	55.9	Mean	27.20	30.05	0.10	0.751	2.29	0.024
			SD	6.32	6.42				

rather negative (students who marked 1 or 2); rather positive (students who marked 3 or 4)

This indicates that students who rated the learning with the *BioScientist* positively had more advanced inquiry skills and were more motivated to learn. Regarding the positive correlation between the program evaluation and intrinsic motivation variables, it can be assumed that students with greater intrinsic motivation prefer to deal with scientific thinking tasks since the motivation for learning in this case is the joy that can be discovered in learning and understanding. The positive correlation with self-efficacy may be explained by independent work in the *BioScientist*.

How Do the Teachers Evaluate the BioScientist Digital Game?

Based on the responses from the teachers, the schedule of the program was appropriate. The majority of the teachers found the teacher account on the website, the built-in teacher function, and the teacher's guide useful. In their opinion, the program fits both the curriculum and the 8th-grade biology subject material (Table 10). However, there were also some negative responses to a few questions. We looked for the reasons for these based on the answers to the open questions. The answers to questions 4 and 5 (1 = the teacher account/teacher mode was not useful at all) belong to the same teacher, who, in response to the program evaluation's open-ended question, mentioned lack of time as a difficulty, but also described that she found *BioScientist* interesting and received all the help she could for his work. Presumably, the lack of time was the reason why this teacher did not take advantage of the opportunities offered by the teaching module and therefore did not find it useful. In the other three cases, different teachers marked the value 2 (rather not). The teacher who perceived that one lesson was not enough to discuss the three stations (question 2) also mentioned the lack of time in the open question. In question 3, one teacher rated the teacher's guide as less useful, but his answer to the

Table 9 Correlations between the students' program evaluation and Inquiry Skills Test, BMQ II, BMQ subscales and biology grade (N = 108)

Variables	Inquiry Skills Test	BMQ II	Intrinsic motivation	Self-efficacy	Self-determination	Grade motivation	Career motivation	Biology grade
Program evaluation	0.28**	0.22*	0.21*	0.21*	0.19	0.27**	0.16	0.03

$^{*}p < 0.05$; $^{**}p < 0.01$

Table 10 Results of the *Program Evaluation for Teachers* (N = 5)

Program Evaluation for Teachers' question	*Frequency (N)*				*Mean*	*SD*
	1	*2*	*3*	*4*		
1. To what extent were you able to implement discussion of the tasks?	-	-	5	-	3.0	0.0
2. To what extent was one lesson enough to discuss the three stations?	-	1	3	1	3.0	0.7
3. How useful did you find the teacher's guide?	-	1	-	4	3.6	0.9
4. How useful did you find your own account (on the *BioScientist* website)?	1	-	3	1	2.8	1.1
5. How useful did you find the website's teacher mode (with scene options)?	1	-	3	1	2.8	1.1
6. How well does *BioScientist* fit in with the curriculum?	-	1	2	2	3.2	0.8
7. How well does *BioScientist* fit in with the 8th-grade biology subject material?	-	-	3	2	3.4	0.6

1 = not at all, 2 = rather not, 3 = rather yes, 4 = completely

open question indicated that he did not need the extra help and considered that the program itself is fully usable and understandable. One teacher indicated that the *BioScientist* is less in line with the curriculum (question 6) because she does not teach biology in this way.

Teachers' feedback showed that the program is described as filling a gap in everyday school practice. They pointed out that the supporting texts are also suited to independent learning and that the children liked them and were happy to do the tasks in the program. The presence of the storyline and the structure of the program were highlighted as positive. The majority of teachers had no problems covering the biology curriculum; they were able to fit the use of *BioScientist* into the usual timeframe. One teacher indicated that he had re-evaluated his own teaching practice as a result of the program. He realised that the students were also capable of designing experiments, so he started structuring his laboratory classes differently. At the same time, it was described as a difficulty that the program is not yet compatible with smartphones and that there were sometimes technical problems (e.g. unstable internet).

Discussion and Conclusions

The aim of the research was to create a digital game to develop inquiry skills in a playful way based on the biology curriculum. In this study, we presented the details and the theoretical and practical aspects of the development. When designing games for educational purposes, the challenge is to strike a balance between pedagogical content and game elements for the game to be enjoyable, but also to provide learning (Rooney, 2012). Therefore, to support learning, it is important that educational games have a solid pedagogical foundation (Dorji et al., 2015). Considering this, we designed the *BioScientist* digital game to allow the gameplay and narrative elements to work together to encourage problem-solving and learning (Rowe et al., 2011).

The implementation of *BioScientist* indicated that game-based IBL is suited to developing inquiry skills, with an effect size that is close to medium (Cohen's $d = 0.46$). This result confirms that the game mechanisms and specific game elements we applied (game tips, scoring system, storyline, structured game tasks, contextualised feedback, gameplay-context coherence) support students in performing scientific inquiry. This is in line with previous outcomes (Clark et al., 2009; Filsecker & Hickey, 2014; Gao et al., 2019; Tsai et al., 2019).

However, biology learning motivation was not developed by *BioScientist*, a finding which can be explained by the fact that motivation is shaped by many factors (Wouters et al., 2013). The tasks in the development program are not always easy, and the additional motivational demand characteristic of IBL (Edelson et al., 1999) may also play a role here. Furthermore, the primary goal of the program is to develop inquiry skills. Therefore, simplifying the tasks and making them more playful would jeopardize the development effect. Thus, it was not possible to confirm the generally held view internationally that playful tasks can increase students' subject motivation (Srisawasdi & Panjaburee, 2018; Tapingkae et al., 2020).

By gender, the data analysis showed no significant effect. Therefore, it cannot be stated that *BioScientist* improved boys or girls more. However, the girls rated the knowledge they acquired from the program as significantly better. There may be several factors behind this phenomenon. Gender differences may be related to individuals' cognitive, affective, and behavioural features associated with digital game-based learning, inquiry-based learning, and learning biology (Barab-Tsabari & Yarden, 2008; Paraskeva et al., 2010; Wieselmann et al., 2020). Kuo et al. (2018), for example, found that male eighth-grade students benefited more from an IBL intervention than female students in terms of their motivation and engagement in science learning. Furthermore, male students developed more motivational constructs, recognised the value of learning science, and increased their cognitive, behavioural, and emotional engagement. However, some studies on gamified scientific inquiry (e.g. Tsai, 2018) have reported that gender has no effect on the performance of scientific inquiry.

At the same time, the feedback on the *BioScientist* game and its use in learning is favourable. *BioScientist* was positively evaluated by the students in general. More than half of them thought that the game had helped them to learn and understand the process of scientific investigation, and they also found that the classroom discussions, which complemented individual work at home, were useful in supporting and reinforcing their learning with the digital game. The majority of the students liked the interesting elements related to the curriculum and would like to cover other topics using *BioScientist*. These results support the notion that the inquiry-based tasks are suited to helping students to understand how science works (Constantinou et al., 2018; Schellinger et al., 2019). Based on the teachers' feedback, *BioScientist* can be used well in teaching biology.

The results of this study draw attention to the pedagogical potential of game-based inquiry learning. *BioScientist* can play a preparatory and complementary role in classroom inquiry-based activities by enriching procedural knowledge about scientific inquiry and enabling the acquisition and development of a range of inquiry skills. It contains useful, well-functioning elements that can serve as an example for the construction of other programs. Furthermore, it fits well with the curriculum, adapts to traditional lesson frameworks, and does not require too much extra time.

This study highlights, at the intersection of DGBL and IBL, the need and effectiveness of integrating various instructional approaches in ways that are consistent with specific learning goals – in this case, developing learners' inquiry skills and conceptual understanding, and increasing their motivation to learn.

Limitation

Although the program is suitable for individual learning, we have not ruled out classroom effects. The role of the teacher and classroom discussion needs further investigation. It would also be worth investigating the influence of *BioScientist* on the acquisition of biology content knowledge. The intervention lasted a relatively short time. Results showed that inquiry skills increased during the 6-week intervention. However, it should be noted that it takes longer to develop inquiry skills. Therefore, it would be useful to measure the delayed effect of BioScientist and to extend the study to other samples and additional biological topics.

Future Studies

One of our future steps is a log data analysis, which is a promising trend in educational research. Based on the logged events, it is possible to ascertain whether the sequence of events generated by the students fits a theoretical scheme; the time spent on the task (time-on-task) and the behaviour of the students in using the program in general can also be analysed (Molnár, 2022; Tsai, 2018). Analysis of the log data for the *BioScientist* digital game can provide useful information on performance in specific inquiry skills. For example, we can examine what happened at different stations, how much time they spent on each step, how many gamified points were accumulated, when the students availed themselves of help, and how much help they needed.

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Data Availability The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethical Approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the Institutional Review Board of Doctoral School of Education, University of Szeged (Project No. 16/2018).

Informed Consent All participants took part in the experiment voluntarily and they could withdraw from the study at any time.

Statement Regarding Research Involving Human Participants and/or Animals Not applicable.

Consent to Participate Written informed consent was obtained from the parents.

Consent to Publish Not applicable.

Competing Interests The authors declare that there are no financial or personal competing interests that could have appeared to influence the work reported in this paper.

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