Co-Creational Drone Simulator for STEM Pedagogy: A Flipped Classroom Approach to Develop Engineering and Social Competence in Early Childhood Education

Arthur Schuchter[1], Giovanni Petrarolo[2], Dominik Grießner[3] and Arian Moradi[4]
[1]Department of Computer Science and Engineering, The Arctic University of Norway, UiT, Bodø, Norway
[2]Department of Mathematics, Ludwig-Maximilians-Universität München, LMU, München, Germany
[3]Department of Law and Economics, Paris Lodron Universität Salzburg, PLUS, Salzburg, Austria
[4]Department of Technical Science, Johannes Keppler Universität Linz, JKU, Linz, Austria

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Abstract: This study explores the effectiveness of integrating inquiry-based and gamified learning approaches in a flipped classroom environment to enhance problem-solving capabilities, social competence, and real-world application of engineering and programming concepts among early learners including children with auditory impairments. This is facilitated by providing a drone simulation as part of an overarching drone workshop. To maximize students' engagement with their learning process and therefore ensuring that the transfer of knowledge is as seamless as possible, we intend to transform the traditional landscape of studying based on direct instructions to be a more contemporary co-creational setting.

1 INTRODUCTION

This paper is a direct successor to the publication "Co-Creational Collaborative Game-Based Learning Simulations, Focusing on IT and STEM Education in an Online Flipped Classroom Environment" and aims to build upon work that had already been established.

However, our team recognizes that some elements of the original publication are not compatible with our current work's development stage, hence they are not included in this paper. This especially concerns the framework for the "drone game" which was originally designed as a two-dimensional game with STEM-related components, e.g., physics and mathematics. Shifting the focus at this development stage from broadly teaching STEM-related subjects towards concisely educating students should yield an enhanced user experience and better highlight the strengths of modern educational techniques. Consequently, many previously established in-game features e.g., coins or upgrades have been discarded.

The current project revolves around the creation of a three-dimensional drone simulation, which enables students to virtually assemble and practice maneuvering the drone. After familiarizing themselves with a digital drone, students are encouraged to assemble and fly a physical drone as part of a workshop, effectively translating their gained knowledge from a virtual setting into real world skills.

2 MODERN STUDY METHODS

The perceived lack of engagement associated with traditional learning methods increases the difficulty which students face in their pursuit of acquisition and consolidation of knowledge.

Therefore, it is paramount to consider the exploration and incorporation of alternative means which manage to better captivate the interest of the audience. By implementing gamified and inquiry-based study methods at the earliest level of education this paper aims to spark interest for engineering and information technologies.

Additionally, through the integration of collaborative learning and introducing a flipped classroom setting this paper intends to further the students' social capabilities as well.

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2.1 Beginner Programming Languages

Overcoming the entry barrier for programming skills can be a challenging and frustrating task which leads to many young learners quitting at an early stage. To mitigate this initial difficulty educators and developers have created a variety of languages specifically suitable for children.

Entry level programming languages are typically created using bright visuals and simple interactive parts introducing young learners to the most basic aspects of coding. To further engage with the young demographic, playful elements akin to video games are oftentimes utilized.

In literature, block-based language models can be viewed as a good reference point. These models utilize drag-and-drop mechanics on blocks which represent different commands and actions. By connecting them the user can create a feasible and logical chain of actions which simplifies coding and increases accessibility for beginners and especially younger demographics (Bers, 2018).

Aside from introducing beginners to coding, block-based programming languages can aid to develop computational thinking as writing code encourages logical and critical thinking as well as organized and structured working practices (Wing, 2006).

One prevalent example of a coding language for children would be “Scratch” a block-based visual programming language developed by the Massachusetts Institute of Technology (MIT). Through connecting colorful blocks, the user can grasp fundamental and essential aspects of coding such as declaring variables, creating loops, events, and sequencing. The simplicity of this structure enables beginners to progress towards larger projects like simple games or animations without necessarily having to immediately learn more complex and sophisticated coding languages (Resnick et al., 2009).

These qualities can also be observed in various other block-based programming languages like “Blockly” or “MakeCode by Micro:Bit” which show similarities in their structure and user interface. Such tools can act as gateways into the world of IT as learners progress from block-based programming models towards word-based programming languages corresponding to their proficiency in coding. This is further enhanced by the possibility to translate block-based code into word-based code easing the transition from entry level programming languages to more conventional coding languages like Python or C++ (Weintrop & Wilensky, 2015).

2.2 Gamification

Gamification learning is an educational approach which has emerged by actively leveraging the intrinsically fun nature of games to aid the learning process. The integration of game-related components can positively influence the efficiency of knowledge acquisition as well as the motivation of the learner. Furthermore, it can be stated that educational practices including gamification and game-based learning approaches align especially well with younger demographics due to the widespread popularity of video games (Tobias, Fletcher & Wind, 2014).

Empirical research has indicated that gamified features can be a strong motivating factor for students if it is embedded in a solid engagement strategy, consequently enabling students to better engage with a lecture. Gamification initially provides the student with an extrinsic motivation, for example by allocating a gamified task to the learner. Moreover, as the student is incentivized to actively participate their academic performance will improve which leads to them being more inclined to be intrinsically motivated and develop a passion for a certain topic (Zainuddin et al., 2020).

In literature, practical applications of gamification often include collectible badges as a means of rewarding the student for academic performance similarly to receiving a medal for competing in and winning a sporting event. To achieve the desired motivational effect however, these badges must have the quality to be generally acknowledged by students to be something of value. Consequently, an environment which encourages students to collect badges is desirable. This can be facilitated by not handing out rewards for simply passing the class, but rather having students undergo reasonable effort to obtain them. Specialized websites like the learning management system Moodle already utilize badges as a form of reward for academic performance. Additionally, the website displays the student’s badges on their user profile allowing for comparisons with other peers furthering their motivation (Herout, 2016).

2.3 Inquiry-Based Learning

Furthermore, elements of other learning methods such as inquiry-based learning can be integrated into a gamified setting to enhance educational benefits. Inquiry-based learning is focused on increasing students’ involvement with the lecture by actively emphasizing student engagement regarding questioning and investigating new topics. Moreover, inquiry-based education models lectures are effectively student-centered as learners must formulate questions, conduct research, and reflect on the results of their experimentation similarly to the scientific process (Abdi, 2014).

Likewise, inquiry-based learning models are especially suited for usage in early childhood education as young children are born naturally curious. Enabling young children to actively ask and resolve questions promotes critical thinking and problem-solving skills at an early stage of development. Additionally, studies show that the integration of interactive gamified features and educational software expands the scope of inquiry which supports children in gaining information literacy and competency in IT (Gladun & Buchynska, 2017).

2.4 Co-Creational Learning

Co-creational or collaborative learning illustrates a study method which intends to enhance the learning experience by increasing engagement with the lecture. This is achieved by establishing conditions which allow students and teachers to collaboratively work on new topics and therefore shape the learning process themselves (Bovill, 2020).

Additionally, the procedure of forming groups challenges the students' ability to share authority and accept responsibility equally amongst team members. Conversely, conventional learning methods often create a competitive atmosphere where students are more inclined to best their peers instead of succeeding as a team. Based on this example, it can be stated that the collaborative component expresses itself through achieving a working consensus among the group's members through cooperation rather than competition. The principles of collaborative learning can aid to develop the students' social skills as well as their ability to find sensible compromises which tend to benefit participants even in the latter stages of their careers (Laal & Ghodsi, 2012).

2.5 Flipped Classroom Approach

The flipped classroom approach aims to modernize the learning experience by reversing the conventional teaching format. Changing the way students are exposed to new information by providing them with videos or texts which should be internalized before heading to class enables lecturers to allocate their time in class to support students in their exploration of new topics rather than simply convey information like in conventional learning models. Consequently, learners are required to assume more responsibility for their own learning process which creates a more interactive learning environment (Fredriksen, 2021).

Moreover, literature suggests that the implementation of technology has a beneficial effect on students' motivation and overall satisfaction with the lecture as it effectively caters towards different learning styles. Furthermore, the interactive nature of the flipped classroom model heightens the students' level of immersion with the lesson (van Alten et al., 2019).

However, the upsides of the flipped classroom approach extend beyond just increasing engagement and immersion. Educators can more effectively provide help and feedback to students due to not being bound to their traditional teaching role. Therefore, individual student needs are being addressed in greater detail which significantly bolsters the knowledge retention rate of students (Gannod, Burge & Helmick, 2008).

Currently, the flipped classroom approach is applied across multiple educational settings ranging from primary to higher education. An exemplary implementation in higher education can be seen in STEM-related fields such as mathematics where this model has been adopted to promote critical thinking skills as well as refine students' social capabilities by requiring them to collaboratively achieve certain tasks (Gilboy et al., 2015).

3 FRAMEWORK

The "Air:Bit Drone Simulation" is supposed to complement face-to-face drone workshops primarily aimed at early childhood students with ages ranging from 5-9, who are divided into small groups of 3-4 people as part of the workshop. All activities described in this chapter are completed in such group sizes challenging young learners to distribute authority within their teams and work collaboratively, with the aim to improve their social competence.

Providing a simplistic means to understand the fundamental principles of object-oriented programming as well as engineering is paramount in sparking interest for coding and IT, especially among young age demographics including those yet to gain literacy.

In contrast to its predecessor this paper abandons the broad coverage of various STEM branches at this current stage of development and focuses primarily on engineering-related aspects. This shift in perspective includes the switch from a two-dimensional game to a three-dimensional simulation as the complexity of creating a game hindered the realization of desired educational benefits.

Furthermore, the “Air:Bit Drone Simulation” is exclusively developed for tablets utilizing Unity's Input System for multi-touch support allowing users to control the drone using touch gestures which aligns with the tactile learning experiences we foster in real life.

3.1 “Air:Bit Drone Simulation”

The simulation consists of four stages each increasing in complexity and gradually introducing children to problem-solving and drone navigation concepts.

3.1.1 Stage 1: Drone Assembly

During the first stage users are introduced to the assembly process of the drone in a simple, interactive manner. All components of the “Air:Bit 2” are scattered, as shown in Fig. 1. Consequently, they must be assembled by utilizing touch input to drag-and-drop each part to its proper place.

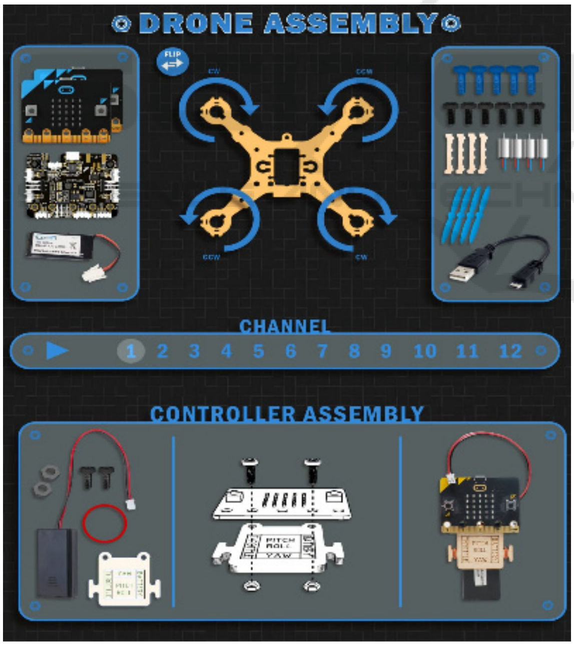

Figure 1: Drone Assembly.

3.1.2 Stage 2: Basic Drone Control

As illustrated in Fig. 2 the second stage features two green circular zones one labeled “Start” and the other marked with a checkered flag to indicate the finish. The player must drag-and-drop the previously assembled drone to the “Start” circle which triggers the “Drone Controller UI”. On the “Drone Controller UI” two buttons are highlighted in green which need to be pressed simultaneously to activate the drone, simulating the start-up process of the physical “Air:Bit 2”.

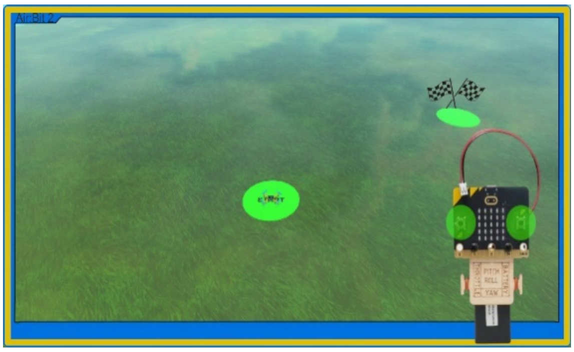

Figure 2: Stage 2 and “Drone Controller UI”.

By incorporating Unity’s touch input system, physics engine, and UI tools this simulation offers an engaging hands-on way for children to familiarize themselves with programming concepts while interacting with a virtual version of the “Air:Bit 2” drone.

Once the drone is started directional control arrows on the UI become active. Furthermore, the buttons used to initiate the drone are now visually showing “Rotor Symbols”, indicating their new function as altitude controls. Correctly utilizing the “Drone Controller UI” allows the groups to control the drone’s movement and navigate it toward the desired location (the checkered flag) concluding stage 2.

3.1.3 Stage 3: Obstacle Navigation

The third stage introduces an obstacle separating the starting point from the landing zones, adding a layer of complexity to the previous task. Therefore, learners must now adjust their navigation strategy to maneuver the drone around the obstacle. Unity's physics engine and collision detection ensures that the drone interacts realistically with the environment providing a challenging yet educational experience.

Thus, the participants’ ability to adapt to new variables is tested, a key component in both programming, engineering, and real-world drone navigation. Aside from simply reinforcing technical skills, attendees are required to achieve this task collaboratively. Consequently, attendees are heavily encouraged to develop a more nuanced understanding of the social capabilities necessary to function as a cohesive team.

3.1.4 Stage 4: Puzzle-Based Command System

The fourth stage shifts focus from direct control to command-based programming inspired by already established block-based programming languages described in chapter 2.1.

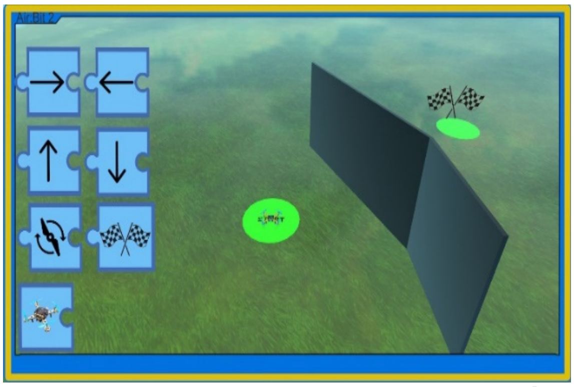

Figure 3: Puzzle-based commands.

Instead of the "Drone Controller UI" the workshop's participants are presented with a set of puzzle pieces as exhibited in Fig. 3 which symbolize different commands:

- Drone Piece: Starting point.
- Rotor Symbol: Adjust altitude.
- Arrow Pieces: Directional movement.
- Checkered Flag: Finish.

To succeed in this exercise, these puzzle blocks must be connected in sequential order forming a command line that directs the drone from the starting point to the finish line. Each puzzle piece corresponds to a pre-defined unit of movement in Unity's coordinate system and multiple pieces of the same type can be used. Once a group believes they have arranged the pieces correctly they drag a final piece marked with a checkered flag to the command sequence. Unity's scripting system then executes the sequence animating the drone according to the assembled command line. If the drone successfully reaches the goal stage 4 is cleared.

The aim of this simulation is to provide a seamless transition from virtual practice to real-world application helping children develop both technical skills and problem-solving abilities. As shown in the images, consistent iconography was used throughout all stages to make the interface intuitive and easy for kids to understand especially regarding working with the puzzle pieces. This design and the interactive nature of the flipped classroom setting help to ensure that the simulation is accessible to all children regardless of their age and reading proficiency.

3.2 Drone Project

The Drone Project was originally established by the "Coding Club Initiative" with the aim of teaching programming skills to all age demographics. A typical workshop consists of assembling and programming the drone and concludes with a physical flying segment to justify the previous efforts of digitally familiarizing oneself with the drone.

In this context, the "Air:Bit Drone Simulation" is designed to be an auxiliary for the workshop where it is supposed to enrich the learning experience by providing an interactive practice environment to young students. Ergo, participants are encouraged to directly translate their gained knowledge from the simulation into a tangible real-world application. Thus, building, programming, and flying the drone are included in the simulation, however, not in this order. Rather, students can utilize the simulation to firstly assemble, secondly fly and thirdly program the drone as can be seen in stage 3 and 4, explained in 3.1.3 and 3.1.4. The reasoning behind this decision was to illustrate the goal of their efforts to the young participants, demonstrating that maneuvering the drone via controller is analogous to communicating with it through a computer language.

Throughout the workshop, traditional teaching styles are disregarded in favor of contemporary pedagogical approaches such as a flipped classroom method. Opposed to classical teaching where the instructor is mainly tasked with presenting students with knowledge, the workshop's facilitator is required to actively involve themselves with the students aiding them to overcome challenges. This approach encourages students to think outside the box and to discover the solution through their own efforts rather than being presented with the right answer by the teacher right away, hence learners actively develop their critical thinking and problem-solving ability.

Furthermore, pupils are required to collaboratively work during the workshop as they are divided into small groups usually ranging from 3-4 students. Therefore, the participants need to designate roles and share responsibility within their team as well as co-creationally decide how to achieve their objectives. As a result, young children are required to find a working consensus amongst themselves which gently introduces them to the concepts of teamwork and succeeding as a collective rather than as an individual, which beneficially influences their social development.

4 EXPERIMENTS AND RESULTS

The “Air:Bit Drone Simulation” is intended to provide a beneficial effect on student engagement, drone assembly capabilities, and fine motor skills while flying the drones.

To validate and observe this impact, ten workshops were conducted in kindergartens and primary schools with each having 16-18 participants from ages 5-9. As part of the workshop participants were divided into smaller groups with 3-4 members.

Additionally, the differences between a traditional learning atmosphere and contemporary study conditions need to be analyzed. Consequently, half of all groups were taught using the “Air:Bit Drone Simulation”. These groups were supported by lecturers in relation to their age and skillset aligning with the concept of a flipped classroom environment. Whereas the remaining participants acted as control groups by experiencing the workshop without the simulation set in a conventional learning environment. Furthermore, they also received support, albeit only to the extent allowed by conventional teaching methods.

4.1 Engagement Factor

The Engagement Factor (EF) represents the degree of involvement and interest that attendees had with the workshop. Furthermore, it illustrates the extent of enjoyment children had whilst participating.

In this context, the children were asked to grade the degree of enjoyment and satisfaction they felt in correspondence to the lecture on a scale from 1 to 5. Whilst 1 represents a thoroughly satisfying experience, 5 indicates them not enjoying themselves at all.

Table 1 separates students into two major categories “Kindergarten” and “Primary School” depending on the student’s current educational institute. Further, this work differentiated between workshops that utilized modern learning techniques as well as the simulation (“with sim”) and those that solely focused on conventional teaching styles (“without sim”).

Consequently, the EF is the mean average of every evaluation ranging from 1 to 5 we received from the participants based on their previously illustrated categorization.

Table 1: Engagement Factor among participants.

Kindergarten		Primary School	
with sim	without sim	with sim	without sim
2	2	1.5	2

Even though every group seemed to enjoy the workshop to the same degree, it is shown that primary school students were having slightly more fun when using the “Air:Bit Drone Simulation”. Furthermore, kindergartners compared to primary schoolers have shown less hesitation in interacting with the material provided by the workshop. Hence, it can be stated that we observed a greater willingness for participation in younger attendees.

4.2 Assembly Process

The children’s ability to successfully and swiftly complete the assembly process of the drone showed the largest disparity in results across all groups. However, it must be noted that the control group (“without sim”) received a physical manual describing the correct assembly while the other group (“with sim”) only had the simulation and its instructions available. Both groups were supported by lecturers within the constraints of their separate teaching methods.

After the receiving their instructions or simulation each group was timed from the beginning to end of the assembly procedure and “errors” were tracked. An action constitutes an “error” if parts were connected incorrectly, resulting in the drone not being able to fly. Analyzing the students’ behavior, it became evident that many attendees had significant issues with the propellers of the drone, especially regarding the pressure applied during their attachment as well as their orientation.

Therefore, in the following tables “propeller errors (PE)” will be measured independently from normal “errors (E)”. In addition, the tables indicate “time until completion in minutes (T)”.

Thus, Table 2 and Table 3 represent the proficiency with which the children are building the drone, while the proficiency consist of the total amount of errors as well as the time it took until completion. Consider that all values in the following tables are also calculated via mean average and rounded to the nearest full number.

Table 2: Drone assembly in kindergarten workshops.

Kindergarten					
with sim			without sim		
PE	E	T	PE	E	T
4	8	30	9	9	38

Table 3: Drone assembly in primary school workshops.

Primary School					
with sim			without sim		
PE	E	T	PE	E	T
1	4	25	7	11	32

On average attendees utilizing the "Air:Bit Drone Simulation" managed to complete the assembly process 7 to 8 minutes faster than their peers in control groups. Furthermore, they recorded fewer total errors and especially the number of propeller errors was significantly reduced compared to students receiving a conventional lecture.

Whilst primary school students "with sim" were more efficient than their kindergarten counterparts, interestingly primary school children "without sim" fared worse in terms of efficiency than kindergarteners "with sim". However, it must be considered that children from kindergarten had a simplified assembly process and additional assistance while primary school students received only assistance when needed. Further, it is important to note that children aged 7-9 had seemingly no difficulty with technical assembly. This demonstrates that future iterations of workshops need to increase the challenge for older age demographics.

4.3 Aerial Competency

Lastly, the children's capabilities to maneuver the drone accurately and safely in real life has been analyzed. Therefore, Table 4 and Table 5 represent their ability to fly the drone by measuring how many mistakes were committed during take-off as well as the number of errors which occurred during flight.

Take-off errors (TE) consist of unsuccessful handling of the controller during the start-up process of the drone. Flight errors (FE) are defined by uncontrolled flying or crashing the drone. All values shown in the following tables are calculated via mean average and rounded to the nearest full number.

Table 4: Drone flying skills in kindergarten workshops.

Kindergarten			
with sim		without sim	
TE	FE	TE	FE
2	8	5	8

It can be seen in Table 4 and Table 5 that the "Air:Bit Drone Simulation" has no significant impact on the flight errors (FE) that occurred during the workshops.

Table 5: Drone flying skills in primary school workshops.

Primary School			
with sim		without sim	
TE	FE	TE	FE
2	4	2	5

However, kindergartners "with sim" had a reduced number of take-off errors compared to their peers "without sim". This trend cannot be seen in primary school children, yet it must be considered that two primary school children had great flying skills already as they possess a lot of video game experience.

5 CONCLUSION

Conclusively, the experiments show promising results regarding a simulation-based workshop embedded in contemporary learning models like the flipped classroom approach.

Further, we conclude that the creation of a learning experience offering students higher degrees of freedom and a chance to take up more responsibilities is very much feasible even for early childhood learners.

Regarding the puzzle-based programming approach highlighted in 3.1.4 not many conclusions can be drawn as to its' viability for future iterations of the simulation as these features need to be expanded to have a deeper, measurable impact on the learning process.

The "Air:Bit Drone Simulation" had a strong beneficial effect on the student's ability to successfully complete the drone's assembly process. Consequently, its suitability as a digital practice environment before real world application is highlighted.

Furthermore, participants reacted well to working in groups which showed encouraging developments regarding social competence.

6 FUTURE WORK

To further enhance the educational experience and expand the usability of our application this paper proposes the following steps to reach these goals.

Firstly, the introduction of multiple assembly modes which aim to introduce three levels of difficulty to the drone assembly process ranging from beginner to an expert mode. The easy mode is designed for early childhood learners featuring a simplified assembly process with fewer parts and larger components for ease of use. Furthermore, normal mode targets elementary to middle school students. Throughout this difficulty a moderate number of parts are available to assemble requiring the student to utilize their problem-solving abilities to a greater extent than on the easiest mode. The last difficulty level is intended for older students aged around 16 and beyond and involves the assembly of every component of the drone mimicking a complete and realistic assembly process.

Secondly, an enhanced simulated flying experience can be achieved by implementing additional features such as the ability to adjust movement values for puzzle pieces with sliders offering the user a more granular control and deeper learning opportunities. Furthermore, Phone-to-Tablet connectivity is a planned feature which allows to connect a smartphone to the tablet or iPad running the program enabling the phone to function as a controller for the simulated drone.

Although this paper explicitly excluded other STEM branches like mathematics and physics at the current development phase, future iterations of the "Air:Bit Drone Simulation" and drone workshops are intended to reintegrate STEM-related subjects that were discarded beforehand.

Thirdly, in future experiments we also aim to observe the effect that the proposed study methods have on long-term retention of acquired knowledge.

Lastly, this paper proposes the expansion of the puzzle-based coding section by increasing the number of playable stages involving puzzle-based commands and creating additional puzzle pieces.

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