SCHOOL OF COMPUTATION,
INFORMATION AND TECHNOLOGY

TECHNICAL UNIVERSITY OF MUNICH

Final report for the interdisciplinary project in Informatics

Blub's Adventure - an Educational Android Application Teaching Numeracy

Maximilian Anzinger
Georg Henning

SCHOOL OF COMPUTATION,
INFORMATION AND TECHNOLOGY

TECHNICAL UNIVERSITY OF MUNICH

Final report for the interdisciplinary project in Informatics

Blub's Adventure - an Educational Android Application Teaching Numeracy

Blubs Abenteuer - eine pädagogische Android-Anwendung, die Rechnen lehrt

Author:	Maximilian Anzinger
	Georg Henning
Supervisor:	Prof. Dr. Frank Niklas
Advisor:	Prof. Dr. Frank Niklas,
	Anna Mues (M.A.),
	Tina Schiele (M.Ed.),
	Dr. Astrid Wirth
Submission Date:	07.06.2023

Abstract

Digital learning has become an important sector of the educational system. There are numerous learning environments to assist children's literacy, numeracy however is broadly neglected. This becomes clear by German law. While children suffering from dyslexia are granted individual support and disadvantage compensation (e.g. additional examination time, or oral examinations), individuals with dyscalculia are not formally protected by the law. This report covers the development of a serious gaming application designed to teach numeracy to children in the preschool stage and support children who have difficulties with arithmetic. The game guides the children through a story in which they are required to master math challenges with increasing complexity. Furthermore, the application provides several tasks that require two players, allowing more parent-child interactions throughout the learning process. The Evaluation shows that the game should offer a deep learning experience and could be a feasible candidate to support future studies on learning applications aimed at children with dyscalculia.

Contents

1. Introduction

Both dyslexia and dyscalculia, have been researched by numerous scientists across the globe ([1]–[6]). Nonetheless, the latter seems to be under-represented in publications as well as public media. Searching for the respective terms in different engines (dyscalculia: Google-$\sim$3.4M, Google Scholar-$\sim$30k, JSTOR-$<$500; dyslexia: Google-$\sim$191M, Google Scholar-$\sim$383k, JSTOR-$>$9300) makes this evident. Therefore, it might be necessary to raise further awareness on the topic. Research indicates that early childhood seems to be the most promising time frame to intervene [7].

Technological devices play an important role in this modern age. This even applies to young generations. The integration of computers, smartphones, tablets, smart-home, etc. into our daily life has changed the way we interact, communicate, and even learn. Whilst offering many new opportunities, technology also created new challenges, especially considering the domain of education. However, digital education is mushrooming, be it in classrooms or at home. Research repeatedly covers serious games, a relatively new way of learning that was not imaginable before this era of digital progress. This approach combined with the already mentioned necessity to promote children with dyscalculia raises our two research questions:

RQ1: How can a serious game support early childhood numeracy in a playful way and can it be used to support children with dyscalculia?

RQ2: How to develop an application for preschool children to learn the fundamentals of numeracy?

2. Related Work

Before the development of an e-learning application, it is necessary to specify and analyze the target group, learning environment, and learning goals. This chapter focuses on **RQ1:** How can a serious game support early childhood numeracy in a playful way and can it be used to support children with dyscalculia? Therefore, a literature review will be conducted to extract key features that are essential for the later developed serious game.

2.1. Dyscalculia

"Dyscalculia refers to acquired difficulty with performing simple mathematical calculations that is inconsistent with general level of intellectual functioning [...]" [8]. Contradictory to the previous classification as a specific developmental disorder of scholastic skills according to ICD-10 [9], it is now considered a neurodevelopmental disorder (ICD-11 [8]), such as ADHD, autism, and Tourette's syndrome [10]. Jacobs and Petermann consider genetic predispositions, cerebral maturation disorders, psychological factors (e.g. speech, executive functions, mind, spacial construction, perception, and sensorimotor abilities), psychosocial factors, and didactic factors potential causes for dyscalculia [11]. Furthermore, their work suggests that dyscalculia has an impact on educator-child as well as parent-child interactions, experiences with peers, and mental disorders. Likewise, these factors also can be an unfavorable influence on the disability itself.

While serious games may not be able to properly address mental disorders or the scholarly environment, it is certainly possible to design the game to account for other key factors to support children with dyscalculia. As pointed out parent-child interactions play a significant role. Hence, a serious game should incorporate features to create a learning scenario, so parents have to interact with their children. This could be achieved either by cooperation or friendly competition. Nonetheless, it should be emphasized that the experience during and after the game must have a positive outcome for both participants to strengthen the relationship rather than further separation.

2.2. Learning Environment

An essential preliminary consideration for the design of a serious game is the differentiation between distinct learning environments. Applications intended to be used in formal settings generally can rely on the presence of an instructor. Hence, trained professionals can intervene or supplement missing information if needed (e.g. lack of prior knowledge). On the other hand, learning games without any supervision necessarily have to account for such scenarios during the creation process. Therefore, significantly more attention to detail is required to achieve a proper learning experience.

Research suggests that education should already start in the early childhood stages. Heckman emphasizes the importance of investing in early childhood education based on the long-term payoff (see Figure 2.1) [12]. This claim is supported by Magnuson & Duncan [13]. Both sources agree that education can be an equalizing factor to support disadvantaged children, thus, reducing the significance of socioeconomic status [14]. Based on data published by multiple researchers an application targeting early childhood should therefore account for an informal learning environment [15]–[17].

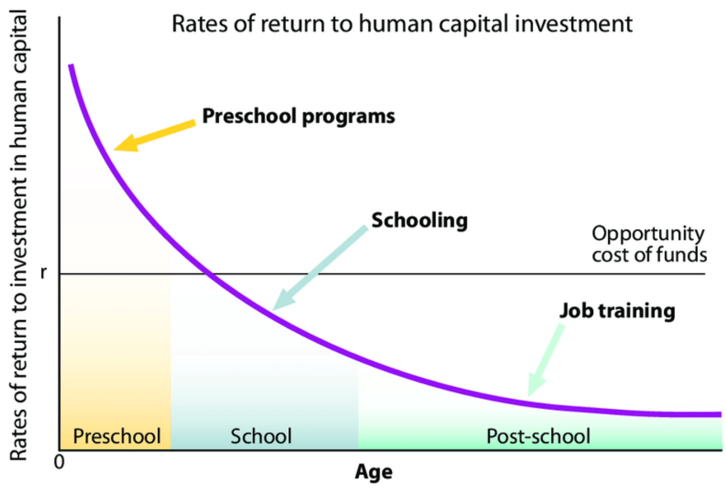


Figure 2.1.: Rates of return to human capital investment in disadvantaged children. (Source: [12])

According to Niklas & Schneider the Home Numeracy Environment (HNE) predicts mathematical competencies [18]. However, several factors may impact the quality of the HNE provided by families. First of all, Niklas & Schneider state that families with a background of mathematical disabilities tend to only allow for adverse HNE. Hence, an application used in HNE should not depend on guidance from parents. It should be noted that this does not contradict the previously mentioned importance of parent-child interactions (Section 2.1). However, it suggests that there should be a differentiation between the process of acquiring new knowledge (e.g. learning new numbers) and repetition (e.g. strengthening the knowledge by playing a motivating game together). On the other hand, the quality of the HNE is also influenced by the socioeconomic background of the family. Given that technological solutions generally require specific hardware availability and affordability must be taken into account to be of use [19], especially to families with lower socioeconomic status. Hence, a serious game should be designed to run on hardware that is most likely already owned or at least easily obtainable, relatively low cost, and preferably versatile (applicable for other or similar use cases).

2.3. Motivation

Research agrees on the importance of motivation for learning success [20]–[23]. According to Fryer & Bovee, lack of motivation may induce deficits in task value and ability beliefs [20]. This behavior could already be observed in prior research on students' willingness to participate in compulsory online homework [24]. Literature commonly suggests that it is the instructors' responsibility to foster students' motivation [21], [23]. However, for an informal learning environment, this is not possible. Therefore, e-learning environments must implement methods to regulate learners' motivation.

One of the models to promote motivation among students is the Attention Relevance Confidence Satisfaction model (ARCS) by Keller [21]. The acronym ARCS consists of the four terms that Keller used to classify motivational concepts and theories. Future work [25] expanded the model to account for volition [26] and self-regulation [27], [28]. Nonetheless, the original model covers a large area of the field and is suitable as a foundation to improve learners' motivation in learning environments. *Attention* describes the necessity of students' curiosity which can be achieved by pointing out a lack of knowledge. Furthermore, the presented content must be meaningful to the individual, such that there is a desire to close the discovered gap (*Relevance*). Once students are inspired to actively participate the goal is to maintain motivation. Kleitman et al. argued that improved self-confidence can positively impact further education [29]. Therefore, learning tasks must be achievable, be it in terms of time or complexity. Hence, learners get the chance to build *confidence*. Finally, according to Keller motivation will be amplified by *satisfying* outcomes of learning tasks. Either the achievement of personal milestones or extrinsic reinforcement can prove to be beneficial for students' mentality.

To address attention and relevance without the presence of an instructor, the application should therefore incorporate this information into the storyline. On the other hand, the design of the exercises and the feedback ought to foster confidence and satisfaction.

Research indicates the significance of trust in education [30]. Wang criticizes that particularly in environments without face-to-face interactions, students still must cope with worries like losing time and money or giving away personal information [31]. In addition, Wang argues about the necessity of trust for effective commitments. Given the importance of trust in digital learning environments, Wang promotes her framework to build and maintain students' trust. Uppal et al.'s publication [32] about their E-learning Quality Model supports the claims made by Wang. The framework covers 12 trust-inducing factors, grouped into four domains: *credibility*, *design*, *instructor socio-communicative style*, and *privacy and security*. A depiction of the framework can be seen in Table 2.1.

Although Wang's research is focused on online learning environments the findings may still apply to this specific use case. For instance, the appeal for high information and design quality agrees with the other sections covered in this work. Furthermore, the game should include contact details of the physical entity behind the application and respect privacy and security concerns by storing as little information as possible and if necessary in a secure manner.

2.4. Cognitive Structures and Processes

For the development of digital learning environments, it is important to study how learners gather and process information. According to Mayer learning with multimedia is structured into three principles [43] (Figure 2.2). Firstly, learners acquire audio and visual information via two different channels (*dual-channels principle*). This coincides with the findings by Paivio [44]. Hence, the learner's eyes perceive visual information (e.g. text, tables, images) while ears allow us to capture the audio signals (e.g. speech, music). Both channels may receive information concurrently. However, studies agree that learners can only process a limited amount of information (*limited-capacity principle*) [45], [46]. Therefore, a learner must select bits of information for further processing. Lastly, Mayer points out that after the selection of information, the learner must organize and construct a verbal and visual model. Combining these models and integrating prior knowledge impacts the learning outcomes significantly (*active processing principle*) [47], [48].

Since the target group of this specific application are children in the preschool stage, the game must be designed for illiterate users. Therefore, written words have to be replaced by intuitive pictograms. Hence, sensory overload by visualizing too much text

Table 2.1.: A socio-technical framework of trust-inducing factors in online learning. (Source: [31])

Dimensions	Trust-inducing factors	Sources
Credibility	• Prior positive experience with the online learning system or the instructor • Good reputation of the online learning system or the instructor	[33], [34]
Design	• High information and design quality of the online learning system • Good accessibility and usability of content and tools in the online learning system • Display of contact details of the instructor or the physical entity behind the online learning system	[35]–[37]
Instructor socio-communicative style	• Assertiveness of the instructor • Responsiveness of the instructor • A sense of care and community created by the instructor	[38], [39]
Privacy and Security	• Disclosure of understandable adequate privacy and security policy statement • Use of security mechanisms (e.g. the secure HTTP protocol, encryption, secured logging system) • Compliance with third-party privacy assurance or standard (e.g. US-EY & US-Swiss Safe Harbor Frameworks, IEEE LTSC) • Reliable and timely access to the online learning system	[35], [40]–[42]

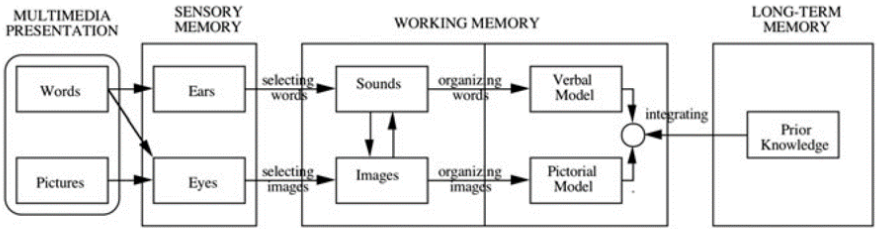


Figure 2.2.: A Cognitive Theory of Multimedia Learning. (Source: [43])

at once is of no concern. However, the provided material should still take advantage of both channels.

The *active processing principle* suggests an episodic structure of the content. Therefore, the story should incorporate this structure by dividing the overall learning goal of the application (basic numeracy) into major learning goals (e.g. numeric domains) represented by sections of the story. Moreover, each section should follow an organized strategy to allow learners to acquire new knowledge, practice the newly learned skills, and finally integrate prior knowledge.

2.5. Instructions

Guiding a learner throughout the process becomes increasingly complex in unsupervised digital learning environments. Since there are no possibilities for interventions and adaptations based on expert observations, it is critical to design a thoroughly thought-out set of instructions during the development. Similar to the *limited-capacity principle* (2.4) also Cognitive Load Theory (CLT) argues about limitations of the working memory capacity [49]. CLT categorizes cognitive load into three sections:

- *Intrinsic Load*: the complexity of the task based on the number of conceptual elements that have to be held in the mind simultaneously to solve a specific task [50]. Furthermore, Plass et al. point out that prior domain-specific knowledge might impact learning success.
- *Extraneous Load*: cognitive load caused by (possibly ill-posed) instructions and the learning environment in general that do not directly correspond to the acquisition of knowledge [51].
- *Germane Load*: processing, construction and automation of schemas [52].

Following these criteria, it is immediately apparent that solving problems induces a relatively high amount of extraneous load while comprehending examples leaves

Table 2.2.: Three goals of instructional design. (Source: [50])

Cognitive theory of multimedia learning	Cognitive load theory	Description of cognitive processing
Reduce extraneous cognitive processing	Reduce extraneous cognitive load	Cognitive processing that does not support learning the essential material
Manage essential cognitive processing	Manage intrinsic cognitive load	Cognitive processing aimed at mentally representing the essential material
Foster generative cognitive processing	Foster germane cognitive load	Cognitive processing aimed at mentally organizing the representation and integrating it with existing knowledge

more room for germane cognitive load assuming intrinsic load takes up equal portions of both approaches. Hence, there must be a differentiation between problem-solving and learning fundamentally new material. Therefore, CLT introduces three goals of instructional design: *reduce extraneous cognitive load*, *manage intrinsic cognitive load*, and *foster germane cognitive load* (Table 2.2) [50]. Future work by Mayer [43] about the design of e-learning environments further elaborates on these goals. Although Mayer's publication is primarily focused on older target groups, similar strategies can be applied to this project.

In the domain of *reducing extraneous processing*, the goal is to eliminate all unnecessary side information and simplify the representation of it. Mayer [43] stresses how important it is to assist the student in his selection process of the data. Signaling to the students which elements are most crucial can be done by arrows, coloring, or other similar formatting features. Although at first glance redundancy of information might seem to be overwhelming for students, it can also help learners to perceive information more efficiently. Explaining a graphic or animation in speech rather than written words allows the students to gather information about the topic over both the visual and audio channels at the same time (see Section 2.4). Furthermore, if there is no plausible visualization of content as a graphic, recounting and describing key facts in voice adds essential value to learning [53], [54], especially when explained differently [55].

Since the target group of this work is an illiterate user base, there is little need to account for written words. Nonetheless, the strategy of using speech as well as animations, such as arrows or other graphics (e.g. pointing fingers), at the same time can be used to cater to both channels. Furthermore, this suggests that different representations of the same principle may improve learners' abilities to conceptualize the material. Hence, to promote children's numeracy, various depictions of numbers (e.g. dots, dice, lines, or fingers) should benefit the learning outcome. Furthermore, also repeating exercises or confronting learners with slight alternations of the exercises may be favorable.

To *manage essential processing*, instructors should pay attention to structuring their lectures into processable segments. Research [56], [57] has shown, that "students who learned with segmented lessons performed better [...] than students who learned with continuous lessons" [43]. Given the limitations of working memory, learners must get enough time to fully process the newly gained information to allow for discovering correlations between the learned theories. Furthermore, pre-trained students seem to be more successful in multimedia learning environments, since learners get the chance to reiterate basic knowledge and are already familiar with key concepts and the terminology [43].

This reinforces the previously proposed episodic structure of the content (see Section 2.4). Furthermore, it implies the meaningfulness of strategically placed breaks from learning to achieve an adequate stress and recovery cycle. This coincides with the findings by Kuckeland et al. [58]. One possible implementation might be to switch from a single-player activity (focussed on learning something new or repetition) to a multi-player setting (repetition with a main focus on a rewarding experience) possibly against peers or parents (see Section 2.1).

Finally, *fostering generative processing* can be achieved by methods similar to the descriptions of Keller [21] and Wang [31] (see Section 2.3). The relationship between learner and instructor plays a significant role in the success of digital learning environments. According to Mayer, methods like using an appropriate but not too formal language style, integration of an onscreen (human-like) agent in videos or animations, and personal attention can improve the situation [43].

2.6. Design Goals

Based on the findings of the conducted literature review we can state our major design goals for the development of the serious game (see Table 2.3). Since the target group of the application are children with dyscalculia, the literature suggests the special role of the parent-child relationship [11] (DG1). Hence, the game should encourage such interactions. Nonetheless, children should still be able to use the app independently (DG2). This becomes increasingly important since the vast majority of the participants are expected to be illiterate (DG3). Furthermore, the used software architecture should take existing infrastructure and affordability into account (DG4).

To improve and maintain motivation we intend to implement a story that raises attention and points out the relevance of the learning material (DG5). Furthermore, the various exercises a player will undergo should provide feedback to foster confidence and satisfaction (DG6). Moreover, the application should incorporate features to gain and maintain trust to allow for effective commitments (DG7).

To manage essential processing, the story should be separated into sections to structure the learning process (DG8). Moreover, all unnecessary side information should be removed and understandable representations ought to be used to reduce extraneous processing (DG9). This extends to the usage of a variety of different representations to allow for better conceptualization (DG10). Finally, we intend to strategically incorporate breaks from learning (e.g. fun-focused multi-player session) to achieve an adequate stress and recovery cycle (DG11). Literature indicates the benefits of onscreen (human-like) agents [43]. Therefore, the game should utilize a virtual companion which may be used to tell the story and may also act as a virtual instructor (DG12).

Table 2.3.: Design Goals

Goal	Description	Section
DG1	Incorporate features to foster parent-child interaction (e.g. cooperation or friendly competition)	2.1
DG2	Ensure usability in the absence of parental guidance	2.2
DG3	Ensure usability for illiterate users (intuitive pictograms and animations)	2.4
DG4	Utilization of a software architecture that is able to run on hardware that is most likely already owned or easily obtainable, relatively low cost, and preferably versatile	2.2
DG5	Provide a story that raises attention and points out the relevance of the learning material	2.3
DG6	Create exercises and feedback that foster confidence and satisfaction	2.3
DG7	Build and maintain trust in the learning environment (e.g. display of contact details)	2.3
DG8	Separate the story into sections to structure the learning process (learning goals)	2.4, 2.5
DG9	Eliminate all unnecessary side information and simplify the representation of it	2.5
DG10	Utilization of multiple representations of the same principle (e.g. dots, dice, lines, or fingers to represent numbers)	2.5
DG11	Incorporate breaks from learning (achieve an adequate stress and recovery cycle)	2.5
DG12	Integrate onscreen (human-like) agent	2.5

3. Implementation

The Goal of this interdisciplinary project (IDP) was to develop an Android app called "Blubs Abenteuer" (engl. Blub's Adventure) (BA) that teaches preschool children the numbers from one to 20 and basic calculations (i.e., addition and subtraction) in that range. To archive this, the core feature of the app is a story mode telling the tale of the green alien Blub who crashes with its UFO and needs the child's help to repair it. The repair is done by solving a range of mini-games with increasing difficulty. After completing the story, it is possible to further practice with randomly generated games.

This chapter will first show what tools we used and why and later explain the structure and functionality of the app, as well as the major problems experienced during development.

3.1. Used Tools

To develop this app, we used the Unity games engine. Unity is a professional, state-of-the-art game engine and free to use for students and small projects [59]. We have chosen it since it provides an easy-to-use graphical editor for scene and graphical user interface (GUI) editing, which is an important part of app development for children. Additionally, Unity provides easy multi-platform build support including Android and Windows, which is useful for testing and delivering the app to many different systems, and hence, supports achieving DG4 (see Table 2.3). Further, Unity was preferred over similar game engines like Unreal and Godot because of our previous knowledge with it. For writing the C#-scripts used in Unity, we used Microsoft Visual Studio Community 2019 because of its built-in support for Unity.

Since BA is supposed to be used on a Samsung Galaxy 2019 10.1" tablet with a screen resolution of 1920x1200 pixels, all assets and videos for the app were optimized for this resolution. However, the app uses Unity's scaling canvas feature allowing it to work with most other screen resolutions as well. All assets were created using the Adobe work suite. Illustrator, Photoshop, and Animate were utilized to create 2D assets and sprite sheets for animations, Audition for audio recording, and Premiere Pro and After Effects for video editing.

The Unity project including the game code, as well as builds for Android and Windows can be found in this GitHub repository [60]. Further, a whole play-through of the game showing most of its features can be found in this YouTube playlist [61].

3.2. The App

This section will show the different parts of BA and explain their functionality as well as some high-level implementation details. First, the main menu will be described, followed by an overview of the different mini-games and the story mode. Finally, a short explanation of the options in free-play mode will be given.

3.2.1. Main Menu

Child Main Menu

When starting the app, first the child main menu shows up, which can be seen in Figure 3.1. This menu is designed to make the game playable for a child, even if its parents aren't available to help and without the need to read anything, supporting DG2 and DG3 (see Table 2.3). Therefore, this menu allows to access almost all features: the story mode, the quick-play mode, a simplified version of the free-play mode, and a "cinema" to re-watch videos from story mode. The story mode is the core feature of BA and will be explained in depth in Subsection 3.2.3. To access it the largest button with the opened book can be clicked. In quick-play mode, the child can play a row of randomly generated mini-games. This mode can be accessed using the bottom left button displaying a running rabbit. With the button right to it displaying puzzle pieces the simplified free-play menu can be accessed. From there the child can choose a specific mini-game for one or two players without further configuration. However, both options are locked until the story has been completed for the first time or the mode is manually unlocked by a parent (further information can be found in the next section). If unlocked early the difficulty of the games depends on the currently reached state of the story and the games won't confront the child with numbers it hasn't learned yet in story mode to meet DG6 (see Table 2.3). In addition to the options mentioned before, the child main menu contains another two buttons. The smaller one next to the start story button allows to re-watch videos from story mode after seeing them there for the first time. The video selection menu can be seen in Subsection A.1.1. Finally, the button in the top right corner showing "Wechsel zu Elternmodus" (engl. swap to parent mode) leads to the parent main menu described in the next subsection. To prevent the child from changing modes by accident, the button has to be held for three seconds. To visualize this procedure a red progress bar appears while tapping the button down.

Figure 3.1.: The child main menu with locked quick-play and free-play modes.

Parents Main Menu

The first time the parent mode is accessed a page with information about the app is displayed. From this screen, the app's imprint can be accessed (both screens can be found in Subsection A.1.2). The information presented on those pages helps the parents to build up trust in the learning environment given by the game (DG7 (see Table 2.3)). Further, a tickbox allows the parents to skip this page on future menu changes. To reach the main page in parent mode seen in Figure 3.2, the button in the top right corner featuring a house can be used. This main page allows the parents to access all parts of the game except the menu to re-watch videos mentioned in Subsubsection 3.2.1. The question-mark button in the top right corner leads back to the information screen, while the button next to it can be used to quit the game after confirming it on the following page. With the wider button directly below it is possible to return to child mode. The first button in the left column starts the story mode. Its label changes depending on whether the story has already been started ("Geschichte fortsetzen", engl. continue the story), or not ("Geschichte starten", engl. start the story). The next button starts the quick-play mode mentioned in the previous subsection, as the label says ("Schnelles Spiel", engl. quick play). However, in parent mode, the difficulty can be selected by the user and does not depend on the story's progress. Additionally, the representation of numbers can be chosen (more about number representations can be found in Subsection 3.2.2). The third button, "Freies Spiel" (engl. free play), allows to access the free-play mode. This mode is quite similar to quick play but allows the parents to apply more in-depth options on the mini-games. More about the free-play mode can be found in Subsection 3.2.4. Like in child mode quick-play and free-play mode are locked until the story is completed or the modes are unlocked in the options.

Figure 3.2.: The parent main menu with everything unlocked.

The final button "Optionen" (engl. options) leads to the options menu apparent in Figure 3.3. From this menu, it is possible to enter multiple predefined codes (first option) that enable the parents to reset the story, move the story progress to certain points, or lock/unlock quick-play and free-play mode or the video skip button. For a successful code input a randomly generated addition task in the range of 40 to 500 has to be solved first to protect children from accidentally using this option. This menu can be found in Figure A.4. The second option allows overriding audio output for numbers, which by default depends on the level of help provided by the game and the progress in story mode. The level of help is part of the help system (described in Subsubsection 3.2.2) and can be changed manually using the last option. Next to each of the options, a question-mark button allows the parents to read additional information about the options. For the first point, e.g., it shows the available codes with a short description of each.

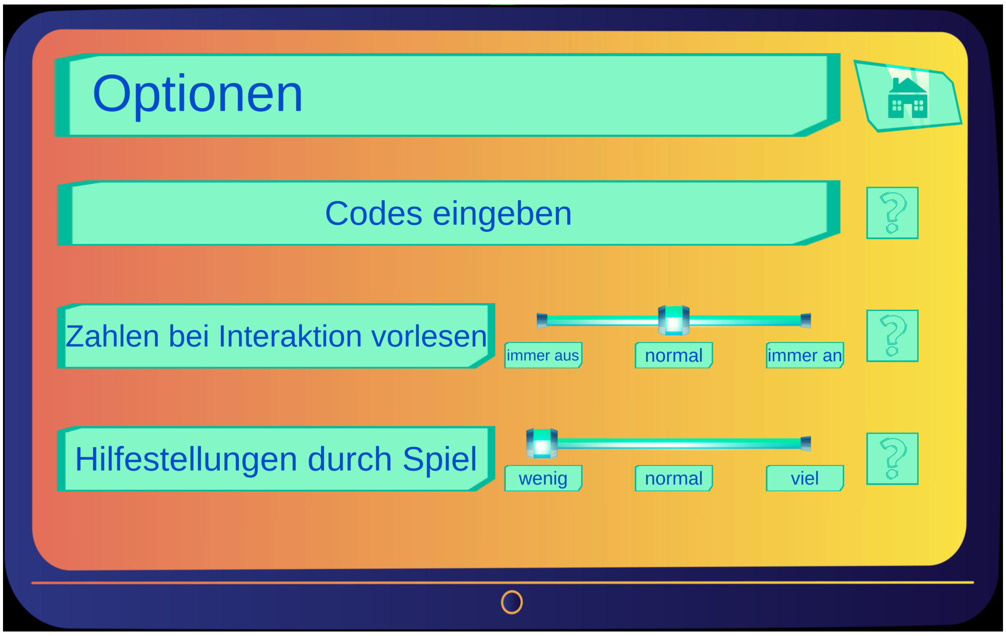


Figure 3.3.: The options menu accessible in parent mode.

3.2.2. Mini-Games

BA features a total of six different types of mini-games, where half of them offer an additional two-player/versus (VS) mode to play with (or against) the parents or older siblings, which supports DG1 (see Table 2.3). Examples for all mini-games can be found in Subsection A.1.4.

- **Add**: Given a target value the player has to find pairs of numbers that add up to it. This can be done by dragging and dropping from one value to the other and is visualized by a line between the current finger position and the initial number-object. Successfully matched pairs will disappear after a short time. There might be additional numbers without matching counterparts to increase the difficulty.
- **Connect(VS)**: The Goal of this game is to connect sums (or differences) of two numbers with the corresponding solution value. There might be between one and 6 pairs to be connected. Tasks and solution values are separated into two columns. Successfully connected pairs will be highlighted in green and connected by a purple line. In VS mode, a vertical line separates the child (left) and parent area (right), and both will have an equal number of tasks. The separating line consists of two colors, green for the child and purple for the parent, to show

which side of the play area belongs to which player. The values for parents might reach up to 100 independent of the game's difficulty.

- **Count(VS)**: In this game, the numbers have to be pressed in the correct order, either increasing or decreasing. The requested order is visualized by two number symbols in the top left corner above the play area. Completed numbers will be highlighted in green, while the last correctly pressed number is highlighted in blue. In VS mode, the play area is again separated by a vertical line and parent values might reach 100.

- **Insert**: For this game, an either increasing or decreasing number line is generated at the top of the play area. In that line, at least one number is missing and at least one number is present. The goal is to fill the gaps in the number line. Therefore, fitting values have to be selected using drag and drop. There might be multiple numbers fitting one gap and numbers fitting no gap at all. To show whether or not the line is increasing, the same visualization is used for count games. An example can be seen in Figure 3.4. After completing the game, the numbers of the line will be read to the player accompanied by a small animation.

- **Memory(VS)**: This game works like classic memory. Number cards are placed with the reverse side up in the play area. The player has to pick pairs, which will turn around revealing their values. If both values match, the cards will stay with the front side up, otherwise, they turn back to hide the values again. The game ends after finding all matching pairs. Pairs will either consist of two set representations or a set representation and a number. In VS mode, indicators show what players turn it is. The player changes after each wrong pair and stays the same when successfully finding one. Further, found pairs are highlighted in the corresponding player's color and a point counter is displayed for each player.

- **Pairs**: This game is a simpler version of connect. The player has to connect number-objects representing the same numbers, but potentially in different display modes or representations.

All numbers in the games are represented by `NumberObjects` each having a `Display Mode`: set (only visual representation), text (only written number, e.g. "5"), or mixed (both set and text). BA has three different visual representation sets which might be mixed or chosen at random in mini-games: hands, lines, and dice. A complete overview of the objects can be found in Subsection A.1.5. These simple and intuitive representations are taken from previous apps of the "Learning 4 Kids" project [62] target DG10 (see Table 2.3).

Each mini-game type has its script derived from the `MiniGame` base class responsible for game generation and game logic, and each game instance is represented by an `MiniGameOptions` `ScriptableObject` containing all necessary information for the game to be generated. Depending on its configuration, a single `MiniGameOptions`-instance might represent exactly one mini-game (apart from placement of numbers) or a range of different games to be randomly generated. While many options are shared by all mini-games, some only apply to a subset and won't affect other games. An overview of all options can be found in Table 3.1. Before generating a mini-game, the game type specific options will be verified to assure everything will work as intended. Wrong-configured options will be corrected automatically using random values where needed.

Table 3.1.: Mini-game options and effects

Option name	Option effect	Affected games
Game type	the type of the game	all
Min value	the minimum value used in the game	all
Max value	the maximum value used in the game	all
Use explicit values, explicit values	whether to use the explicit values or generate them by random	insert, count(VS), pairs, memory(VS), connect(VS)
Number of values	number of values to be randomly generated if explicit values aren't used	insert, count(VS), pairs, add, connect(VS)
Display mode	how the numbers should be represented: as set, number or both	all
Number representation	which number representation should be used: hands, lines, dices, mix of all	all
Alternative representation	whether to use the alternative representations for five and ten	deprecated: no effect in final game
Increasing	should the numbers in the game increase or decrease	insert, count(VS)
Number of non solution values	number of values not part of the solution	add, insert

Table 3.1.: Mini-game options and effects

Option name	Option effect	Affected games
Use explicit missing values, missing values	whether to use the explicit missing values or generate them by random	insert
Number of missing values	number of missing values to be randomly generated if explicit missing values aren't used	insert
Right side display mode	display mode of the right column	pairs, connect(VS)
Target value	the target value of the game	add
Memory size	size of the memory game, i.e., the number of pairs: small (4), medium (10), or large (14)	memory(VS)
Match set text	whether pairs consist of set-set or set-text representations	memory(VS)
Second representation	second number representation for memory pairs	memory(VS)
Subtract	whether subtraction or addition tasks will be generated	connect(VS)
Number audio active	should number audio be played with normal help level	all

Mini-Game Related User Interfaces

Figure 3.4 shows the screen during an insert game, which only differs in the content of the play area compared to other mini-games. By pressing on Blub in the top center of the screen, the task description audio will be played. It is also played the first time a mini-game type occurs during the story. The question-mark button opens the explanation menu (Figure A.10), where a short video can be viewed explaining to the player what to do in the current game. Those videos are also shown during the story before a game occurs the first time. Those features are designed to meet DG2 and DG3 (see Table 2.3). The button with the house opens another menu that allows the user to restart the current game or leave it (Figure A.11). In that menu, both buttons have an additional button next to themselves to play descriptive audio.

The main part of the screen with the blue surrounding and orange background is the play area. Here, all number-objects and other game-specific elements will be displayed. In the example shown in Figure 3.4, the numbers are presented in mixed display mode. The number-objects with blue surroundings are the given numbers from the number line, while white ones can be dragged on the purple placeholders with question marks. Additionally, insert and count(VS) mini-games feature a display in the top left corner to show the player if the game expects the numbers in increasing or decreasing order. The arrow can be pressed to hear a corresponding audio.

Besides the instructions and numbers, there are no other sound effects in BA. This contributes to achieving DG9 (see Table 2.3). For the same reason, the graphical user interface during mini-games provides only the needed information to understand and play the game.

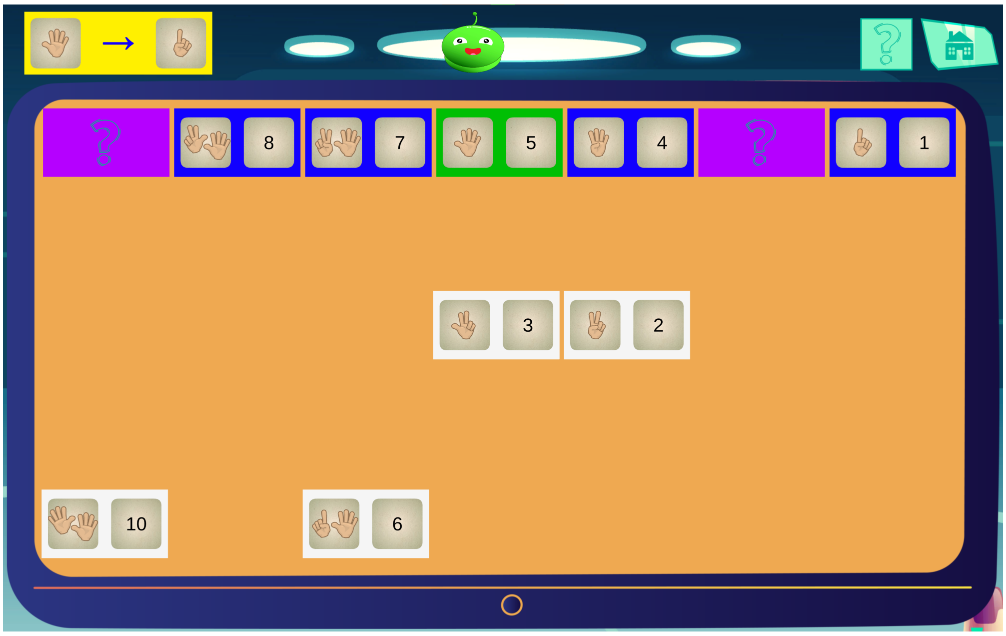


Figure 3.4.: Example of an insert mini-game with one number already inserted successfully.

After completing a mini-game the post-game menu appears. Here, a motivational message will be played and the player has multiple possibilities depending on the current game mode. In Figure 3.5, the post-game menu from a story mode (Subsection 3.2.3) level is displayed. Here, the player may restart the game (button with circular arrow), go back to the UFO to continue the story (button with an arrow pointing to the right), or exercise the last game with a similar, but easier version of that game (button with light bulb). In free-play or quick-play mode, the exercise button is replaced by a return-to-main-menu button, and the continue button - only present in quick-play - starts the next game. Further, the post-game menu features a motivation system. Based on the player's performance a rating from one to three stars is given and the motivational message is adapted accordingly. For the best rating - three stars - a small firework effect is displayed as shown in Figure 3.5 to additionally increase the child's motivation. This supports DG6 (see Table 2.3).

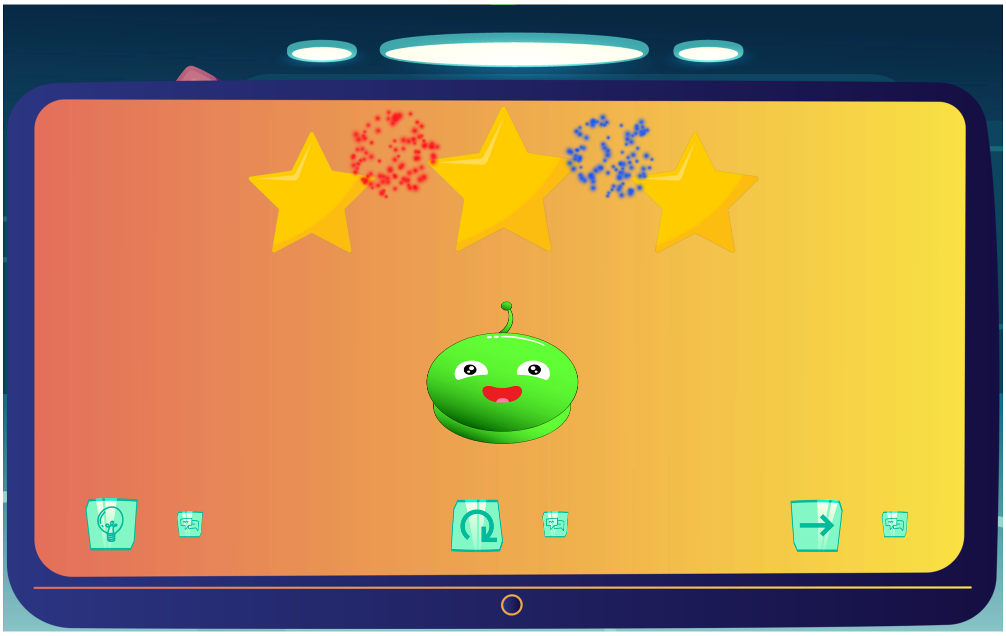


Figure 3.5.: Post-game menu in quick-play mode with all three stars reached

Help System

BA features a built-in help system during all mini-games, that mainly targets DG2 (see Table 2.3). This system has two tasks: helping the child if it's stuck, i.e., if it makes too many wrong inputs in a row, and checking if the child is still playing or it doesn't interact for a certain time. In the latter case, the so-called "still playing menu" will be displayed (Figure 3.6) after there was no interaction with the screen for more than one minute. Blub will ask the child whether or not he or she wants to continue playing. Pressing the green tick button will close the menu and continue the mini-game, while the red cross will abort the game and return to level selection in story mode or the main menu in free-play and quick-play mode.

However, the main task of the help system is to help the player whenever he or she is

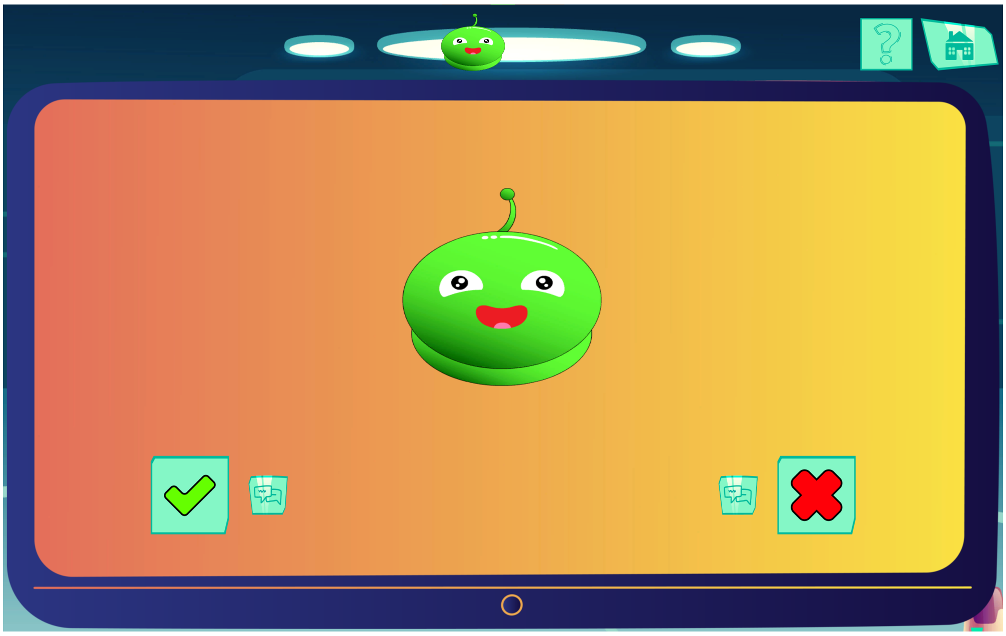


Figure 3.6.: The still playing menu

stuck. Therefore, the system tracks all interactions of the player with the game. Those interactions are divided into correct, wrong, and neutral inputs. Neutral inputs like turning a single memory card around only reset the timer needed to check, whether the child is still playing. Wrong interactions on the other hand increase a counter and trigger the help to be displayed when reaching a threshold. That counter is reset every time a right interaction is recognized. The threshold for displaying help depends on the current game's size (the number of involved numbers) and is decreased every time progress was made during that mini-game down to a minimum of three. Additionally, the initial threshold is influenced by the current level of help. Much help decreases the threshold by one third while little help increases it by the same factor. Further, the level of help influences, whether or not number audio is played on interactions: with more help the audio is always active, with less help never, and with normal help it depends on the mini-game's settings. However, this can be overridden from parents' main menu to always or never enable audio independently from the level of help.

The help system has an adaptive level of help with three steps: more help, normal, and less help. At all times, this level can be changed from the options menu in parent mode (see Subsubsection 3.2.1). During each play session in the story, quick-play or free-play mode the help system manages a skill rating. This rating is a value between minus three and plus five. After each completed mini-game this value is changed according to the player's performance. This can be seen in Figure 3.7. A three-star level increases the rating, while a one-star level decreases it, and a two-star level normalizes it to zero. When reaching minus three or plus five, the level of help is, if possible, decreased or increased, respectively. Otherwise, the rating and difficulty stay at their current levels.

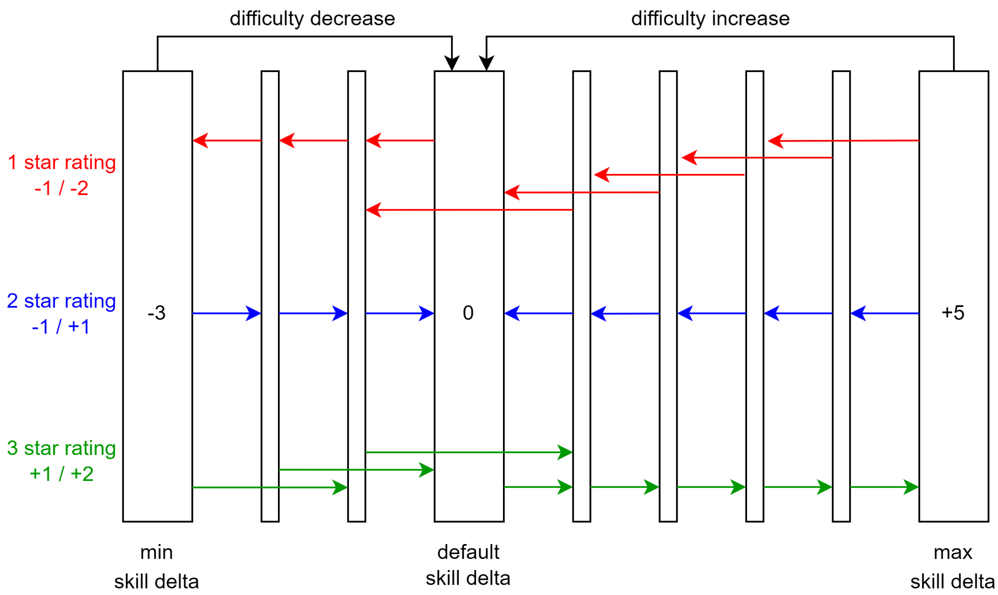
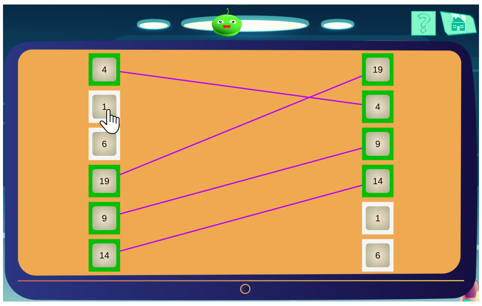


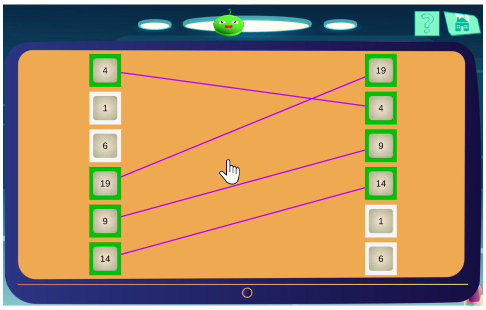
Figure 3.7.: The behaviour of skill rating (skill delta) and difficulty with different star ratings.

The displayed help comes in the form of a hand pointing at number-objects. The hand starts at one object's position, stays there for a moment, and then moves to the corresponding position, where it again stays for a short while. This is repeated until a right interaction is received. The corresponding position of course varies from game to game. It is either another number-object that has to be connected to the first one, or a gap in the number line during the insert mini-game. In the case of the counting game where only one object has to be pressed, the hand pulses in size instead of moving between two positions. Figure 3.8 shows an example of the help during a connect game.

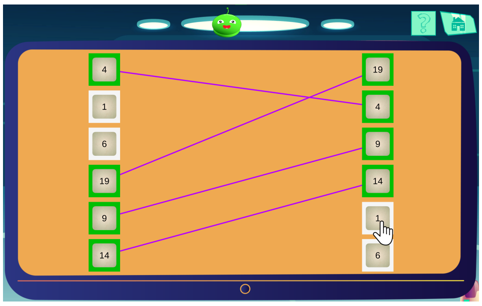
From a technical perspective, the help system is realized using the Unity `EventSystem` with a custom event handler called `IHelpSystem` that provides methods for each type of interaction, decreasing the threshold, and starting and ending a mini-game. Necessary data for the event is stored in `HelpSystemEventData` and `HelpSystemPerformanceData` instances and the event calls are processed by the `HelpSystem` script.



(a) Hand starting at an uncompleted number-object.



(b) Hand moving to the matching number-object.



(c) Hand reaching the matching number-object.

Figure 3.8.: Help system example in a pairs mini-game.

3.2.3. Story Mode

The core mode of BA is the story mode. It tells the story of Blub, the green alien space police officer, who crashes with its spacecraft on Earth at the beginning of the story. After introducing itself, Blub asks the player for help to repair the UFO. Following a room tour through the vehicle to familiarize the player with its structure, the main gameplay starts. The child has to find different objects in each of the spacecraft's rooms. Clicking on one starts a mini-game that has to be solved to progress the story. More details about the content and structure of story games can be found in the section ”Story Games”. Finally, after completing all games, Blub thanks the player and returns home. It leaves the so-called space tablet to the player to further communicate and practice with him or her. This is a reference to the quick-play and free-play modes, which are then unlocked.

Blubs origin as an alien arouses the child's curiosity and hence its attention to the game. Further, the story appeals to the player's willingness to help which supports DG5 (see Table 2.3).

As it could already be seen in the previous sections, Blub is present at any point in the game to support and advise the player, which fulfills DG12 (see Table 2.3).

Story Sequences

The story is told in short videos that can be found in this YouTube playlist [63]. This format was chosen so that the player can repeat a part of the story without wasting time watching parts that she or he already understood. In the game, multiple videos are grouped into larger, logically connected `StorySequences`. During a story sequence, there are only three UI elements present. A left arrow to go back to the last video clip that is only disabled during the first video of a sequence. A circular arrow to restart the current video clip that gets enabled after that clip finished playing for the first time. And finally, a right arrow to continue to the next clip or leave the sequence in case it's the final video. The last button is enabled after the video was played for the first time during a sequence, if the story was already completed once, or if enabled via code input in the options menu (Subsubsection 3.2.1). As soon as a clip stops playing the last mentioned button will start pulsing larger and smaller to catch the child's attention on how to continue.

Figure 3.9.: Example for story sequence user interface

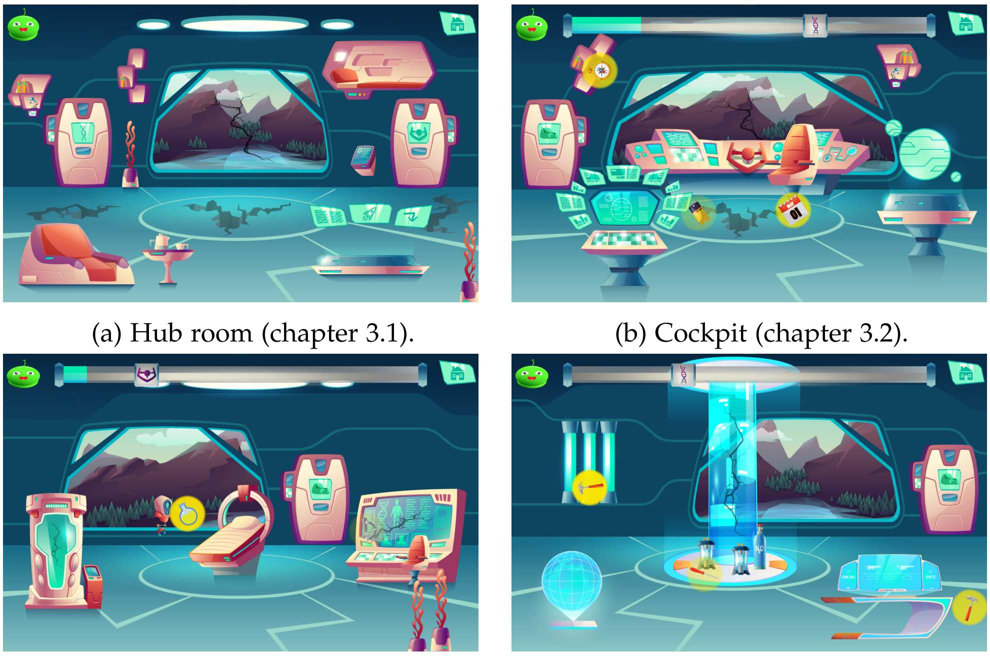
Level Selection

As mentioned before, the level selection is done by clicking on objects lying around in the different UFO rooms. Blub's spacecraft has a total of four rooms: the hub room (Blub's living room), the cockpit, the laboratory, and the engine room. Levels can only be started from the last three rooms, while the hub connects them. Room changes are performed by clicking on the doors. This functionality is also taught to the player during story sequences. Those sequences may be completed like other story sequences by clicking the right arrow button as described in the previous subsection or directly using the door, which behaves like the button during those videos. Figure 3.10 shows a selection of the backgrounds for each room (for a complete overview see Section A.2). Additionally, the pictures show the UI and some objects to start mini-games. Those objects are randomly selected from a predefined set of assets for each room fitting their theme (e.g. cables in the engine room) and have a pulsing yellow background to make them easier to find. Further, by pressing on Blub in the top left corner an audio hint tells the player whether or not there is something to do in the current room. In all rooms except the hub, a large progress bar at the top of the screen shows the current progress to the next repair step. In addition, it displays the symbols of other rooms, if the player has to finish mini-games there first to continue. The house button in the top right corner allows to return to the main menu after confirmation.

Story Games

The story is separated into four learning phases and each room is assigned another learning goal to structure the learning process (DG8 (see Table 2.3)). Further, games are grouped into blocks. For the current game block of a room, all buttons to start a single mini-game are generated at once. In Figure 3.10b, e.g., there are three unsolved levels in the current block. However, the games are started in fixed order independent of the button that was clicked. Further, a block may have other rooms' blocks as preconditions to be played. The first time a certain mini-game appears in the story, the corresponding explanation video is played first and the game starts directly after the video finishes. Additionally, the task audio is played automatically.

The room to start within each learning phase is the cockpit. Here, the player learns about different possible representations for the same values with pair and memory mini-games. This targets DG10 (see Table 2.3). Next is the laboratory, where the order of numbers is taught using insert and count games. The final room to visit is the engine room featuring add and connect mini-games to teach the player connections of numbers, as well as basic arithmetic operations. An overview of all story games and the underlying structure can be found in Section A.3. As mentioned in Subsubsection 3.2.2,



(a) Hub room (chapter 3.1). (b) Cockpit (chapter 3.2).

(c) Laboratory (chapter 3.3). (d) Engine room (chapter 3.4).

Figure 3.10.: UFO rooms with UI at different points in the story.

the content of each story game can be practiced in an optional, easier version after completing it. To support parent-child interaction (DG1 (see Table 2.3)) a VS game appears as the final game of each learning phase and in each room. However, to enable the child to progress even in the absence of its parents (DG2 (see Table 2.3)) an equivalent single-player game can be selected instead.

After each learning phase, the story continues with short story sequences showing the repair progress to the player. Together with the forced room changes during the learning phases, this includes short breaks from learning and hence implements DG11 (see Table 2.3).

Progress System

Technically, the progress system is based on `ProgressStep` `ScriptableObjects`, each having a range of other progress steps as preconditions and the possibility to change the current room's audio output. Further, progress steps are divided into three different types. First, `StoryProgressSteps` containing a `StorySequence` to play videos and optionally ending them with a mini-game. Second, `GamesProgressSteps` responsible for generating mini-game start buttons in the UFO rooms and containing a range of `M` `iniGameOptions` for story games and exercise games. Third, `ScriptedProgressStep`s to execute arbitrary functions using `reflections` for realizing story events like, e.g., background changes. A `ProgressController` is used to manage the different progress steps for each room and save the progress when the story scene is left or the app is paused. For saving, Unity's `PlayerPrefs` are accessed by the `PlayerPrefsController` script. While this approach would allow the manipulation of save data from outside the app because it's saved as clear text, it is a very simple and straightforward choice for this project since save data does not contain sensible data. Further, it can't be expected from preschool children to browse through system data and manipulate random files.

3.2.4. Free-play Mode

As mentioned before, the free-play mode allows parents to customize mini-games to a certain amount. The corresponding menus can be seen in Figure 3.11. First, the mini-game type has to be chosen out of all existing single-player and VS games. Next, difficulty and number representation can be selected like in quick-play mode. Finally, the game can be started right away or some additional options like minimum and maximum value, as well as game type specific options can be adjusted. After starting a game, the free-play scene loads, which looks like the mini-game user interface in story mode. After finishing a game in free-play mode, it is possible to restart the game or return to the main menu. The latter will load with free-play mode options opened.

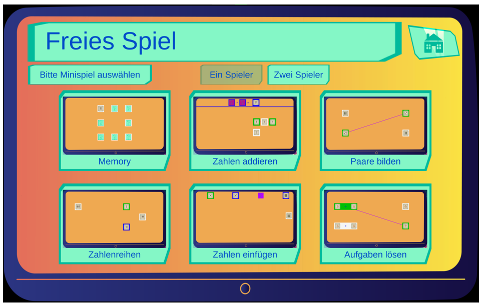
3.3. Problems during Development

Over the time of development, a huge number of bugs and problems appeared, as expectable from a project of this size. Most of them could be solved very fast and easily. However, some problems were harder to identify and fix and will be discussed in this section. First, Subsection 3.3.1 will deal with technical problems, followed by Subsection 3.3.2 explaining difficulties in game design.

3.3.1. Technical Difficulties

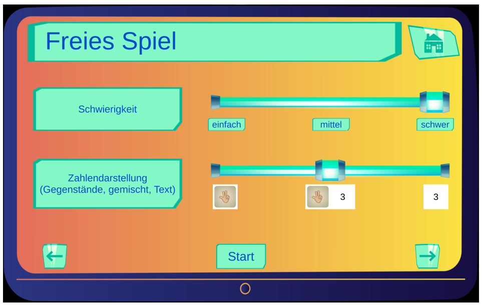
Story Videos crashing the App

Early in development, it was decided to present story sequences as prerecorded and cut videos rather than animating them in Unity. The functionality to display those videos was then implemented a long time before the first story videos could be produced and finished. Because of this, an arbitrary video was used for testing. While testing in the Unity editor everything seemed to work as intended. However, starting a video on the



(a) Mini-game selection from parent mode for single-player games.

(b) Mini-game selection from child mode for VS games.



(c) Basic difficulty settings (only in parent mode).

(d) Advanced settings (only in parent mode).

Figure 3.11.: Free-play mode options menu.

test tablet always caused the app to crash. At first, the problem couldn't be identified until the first story videos were completed and added to the build for testing. With the final videos, everything worked fine on both the tablet and in the editor. Further investigations showed that the initial test video had, contrary to the real story video, two separated audio tracks which was not supported by the Unity video player for Android.

Insert Mini-Game Bug

The insert mini-game was one of the first parts completed for BA and considered as done for a long time. However, some feedback from testers later in development included vague feedback that "something was not working as expected" for that game. The problem - numbers that did fit gaps at one of the ends of the number line were not accepted by the game - could only be identified and fixed sometime later when this quite uncommon edge case appeared during another testing session.

Volume Balancing

Balancing all game audio to a common level was a difficult part of the development because of multiple reasons. First, there were strong limitations for microphone settings due to the lack of a professional recording setup leading to slightly different results for each recording session. Second, it's hard for inexperienced voice actors to keep an equal volume. Finally, the audio in the development environment on PC behaves differently than in the build version for Android. The first two problems could be fixed by extensive post-processing of the audio files, while the last problem is resolved by using Unity's `AudioMixer`.

3.3.2. Design Difficulties

Number Representations

The game's representation of numbers caused a few difficulties during development. The first iteration consisted of an example set using cups as objects, that were placed unordered in the available space. Further, there were two different representations for the numbers five and ten. Five, e.g., had one with five countable cups and one with a container. This was supposed to make the representation of larger numbers more clear. However, feedback showed that the connection between five countable objects and the container representation was not clear enough for the target audience and that unordered objects would distract too much from the game itself. Another problem with cups as representation was their individual size in the representation of a single number. Therefore, it was decided to switch to intuitive objects represented in an ordered way, i.e. hands, lines, and dice. Since the "Learning 4 kids" project [62] had already fitting assets, those were integrated into BA as well. All number representations including the version with cups can be found in Subsection A.1.5.

Another difficulty related to number representations was finding the right compromise between the size of one number-object to interact with and the total number of objects that had to fit on the screen for interesting gameplay. Further, number-objects showed inaccurate interaction behavior on Android devices when touching them near their edges. Those problems could be resolved by exhaustive testing and the introduction of slightly larger hitboxes larger then the visible outline of the numbers.

Feature Changes

During the development of BA, multiple new features were added that weren't planned at the beginning and other features were widely changed. One reason for those unplanned changes was a miscommunication between the involved people caused by the interdisciplinary cooperation of computer science and psychology. Further, the vision of and expectations for the project changed over time. However, this only led to an increased development time but no further problems because there was no hard deadline.

4. Evaluation

Under current regulations in Germany conducting studies and gathering data on children is a notoriously difficult undertaking. Due to limitations in time and resources, this evaluation will analyze whether BA is a feasible candidate to be deployed in future studies on children with dyscalculia in HNE.

4.1. Methodology

The evaluation is based on the work of Hirsh-Pasek et al. [64]. Firstly, the four pillars

- *active, minds-on learning* - physically and mentally active, cognitively active learning
- *engaged learning* - behavioral, emotional, and cognitive engagement
- *meaningful learning* - purpose and relevance, connections to prior experiences
- and *socially interactive learning* - (para)social interactions and relationships

will be analyzed. Furthermore, *scaffolded exploration* (educational context) will be evaluated. We will assign each category a score according to a Likert scale (1-5, low-high) and finally conclude if BA is a high-quality educational application that could be used for further research.

4.2. Analysis

4.2.1. Active, Minds-on Learning

BA utilizes symbolic systems with various representations to visualize numbers (e.g. fingers, dots, lines), that can be manipulated using the touch-screen (drag-and-drop & clicking). Any occurrence of a number is verbally labeled and depending on the mini-game also visualized with the corresponding numeric representation. Additionally, users get an immediate visual response when they interact with a number.

Furthermore, the application promotes intellectual parent-child or peer interactions using the regularly scheduled multi-player mini-games. By allowing the player to choose the rooms to continue solving puzzles and voluntary training games, BA allows for an appropriate level of control and agency. Children's perception of a free choice is further underlined by the possibility to pick between multiple objects in a room to start the next game. Although any choice will result in the same mini-game this is most likely imperceptible by the target group.

Finally, BA avoids any popups or similar features during the mini-games and the story that might cause distraction.

Hirsh-Pasek et al. point out that apps may utilize multiple sensors of the tablet, such as GPS, gyroscopes, cameras, and microphones to allow for more versatile interactions. Besides the touch-screen BA fails to incorporate any of these possibilities. Despite this missed opportunity BA can still be considered to offer an active, minds-on learning experience. Therefore, we rate this pillar with 4 points.

4.2.2. Engaged Learning

As mentioned previously, in BA every physical action offers an immediate response. Furthermore, the feedback system includes labels (stars measuring how successful the task was solved), motivational messages, parasocial displays (jumping Blub animation), and access to new content (in-game progression). In the starship's rooms, the children have to search for objects to start a new mini-game. According to Hirsh-Pasek et al., this can be a rewarding experience. Together these features already provide adequate extrinsic motivation and feedback. However, some of the feedback texts contain phrases that praise the children's intelligence, which might have a negative effect on engagement.

Finally, BA rewards the players' success by giving them more control over what games to play. After completion of the story, the user can select from all the games and difficulties or even play the story from scratch to allow for an open-ended experience. Throughout the game, the story- and learning-sections are clearly separated to avoid any disruptions. Taking these facts into account, BA should present an engaging learning experience that can be rated with a high score.

4.2.3. Meaningful Learning

The story told by BA is an inherently important tool to give meaning to the learning goals. By starting and ending the adventure in a familiar environment (a lake near home) the narrative strongly corresponds to real-life experiences. Additionally, the visual design incorporates various objects that are common in everyday life (cups, books, plants). A key feature of the story is the recurrence of the ”space-tablet” to play mini-games, a fictional, technical device users analogously physically interact with.

This strongly ties connections between in-game and real experiences.

During the adventure, users must solve exercises to repair the crashed spaceship. Therefore, the tasks are embedded into the story, supporting a rich narrative. This extends to the late-game when Blub gifts the fictional space tablet to the player allowing them to interact and keep playing ”remotely”. To create real interpersonal experiences, multi-player games are scheduled regularly throughout the story. Therefore, children get the chance to share their adventures and newly gained knowledge with peers or parents.

We conclude that BA satisfies the requirements to achieve a meaningful learning experience and assign this pillar a score of 4.

4.2.4. Socially Interactive Learning

In BA regularly scheduled multi-player games offer numerous possibilities for face-to-face interactions between users, e.g. parent-child or peers. Furthermore, the videos are designed to be interactive. The protagonist repeatedly asks questions directed at the children and pauses to give time for responses. This also contributes to the relationship between the on-screen agent and the player. Progressing through the adventure together and interacting with the friendly alien should promote a connection that might be beneficial for the learning outcome.

Unfortunately BA lacks any prompts or similar features to encourage players to perform actions away from the screen (e.g. searching for a specific number of objects). Although Hirsh-Pasek et al. suggest including technologies such as video teleconferencing, screen-sharing, draw-boards, or other similar collaborative tools, BA intentionally omits these features due to security concerns without parental supervision.

While implementing some strategies to promote socially interactive learning, there is still headroom for improvements. Overall BA receives a medium score for this pillar.

4.2.5. Scaffolded Exploration

As BA is intended to be used in HNE, external scaffolding should be excluded from this evaluation. To account for the absence of supervisors, the game includes a hinting system to assist users when necessary. Furthermore, the order of the mini-games follows curriculum leveling strategies (Subsubsection 3.2.3). Although BA can not be considered a proper adaptive learning application, the game still keeps track of past performances and adjusts various settings of the hinting system accordingly. Therefore, we assign this category a score of 4.

4.3. Results

In Section 4.2 we found, that BA offers a highly engaged learning environment. Furthermore, BA necessitates children to participate in active, minds-on activities throughout the game and provides a generally meaningful learning experience. Moreover, the app includes features to allow for age-appropriate scaffolded exploration. Hence, these categories achieved a mid-to-high score. Socially interactive learning scored the least points. Nonetheless, BA ranks adequately compared to other popular applications (e.g. Duolingo, Toca Hair Salon Me). A visualization of our results can be seen in Figure 4.1.

Looking at these results, we find that the four pillars achieve mid-to-high scores. According to Hirsh-Pasek et al., this indicates that depending on the quality of the educational context BA falls into the category of either playful or deep learning applications. Taking into account the mid-to-high score of the learning goals (scaffolded exploration), we can predict that BA will likely provide a deep learning experience. Therefore, we can conclude that BA is a suitable candidate to be used for the study of children with dyscalculia and their HNE.

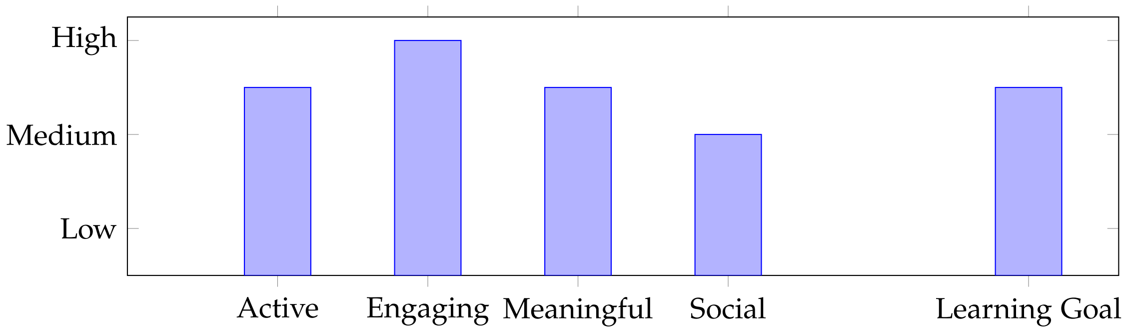


Figure 4.1.: The profile of Blub's Adventure showing how the app rates on each of the four pillars from the Science of Learning and how it rates on furthering learning goals.

5. Conclusion

In this paper, we developed a serious game called "Blubs Abenteuer"(BA) focusing on preschool children with dyscalculia. Therefore, we first reviewed literature (Chapter 2) to answer **RQ1:** How can a serious game support early childhood numeracy in a playful way and can it be used to support children with dyscalculia? From the results of this review, we elaborated a range of design goals (Table 2.3) to guide the development of our application.

In the second part (Chapter 3) we focused on **RQ2:** How to develop an application for preschool children to learn fundamentals of numeracy? The resulting application, BA, fulfills the before-mentioned design goals: By using the Unity games engine it is possible to build the game for many different platforms without great expenditure and hence makes BA accessible for a wide audience (DG4). The game uses pictograms and audio instructions to enable illiterate users, i.e., most of the target audience, to play without the presence of a parent (DG2, DG3). However, optional VS games appear regularly during the story to foster parent-child interaction (DG1). The story around the green alien Blub that needs help to return to his family helps to arouse the child's curiosity and hence raises its attention to the presented material (DG5). Additionally, the story connects seamlessly to the free-play modes where further practice is possible. Further, the story is separated into blocks focusing on different learning goals (DG8) that are separated by small video sequences introducing short breaks to the learning process (DG11). The mini-games make up the main part of the game. They use multiple different representations, i.e., lines, dice, and hands, for numbers (DG10) and feature a help system to support the user if she or he is stuck. After completion, they show a performance rating using one to three stars and a motivational message (DG6). Overall, the game shows relevant information to the player and forgoes unnecessary sound effects that could distract from learning (DG9). Further, Blub is always present on the screen to instruct and help the child (DG12). Lastly, BA features a parent mode with an information page to educate the parents about the app and its intended usage, which helps to build trust in the learning environment (DG7).

Finally, we evaluated BA based on the four pillars presented by Hirsh-Pasek et al. [64] (Chapter 4). The result shows that BA can likely be considered as a deep learning experience and is hence a good candidate to be used in future studies related to children with dyscalculia and the HNE.

For future work, we suggest testing BA with its target audience and using it in fitting studies since this was not possible during the work on this paper. Further, the game could be replenished with new mini-games, e.g., one where the player has to balance out the scales by dragging objects on one side of it. An extension of the story covering the numbers up to 25 or 30 would be possible as well. Finally, the help system could be improved to provide situational audio feedback, i.e., explain how to figure out the displayed help by oneself.

A. Appendix

A.1. Game Menus and Mini Game Examples

A.1.1. Video Selection Menu

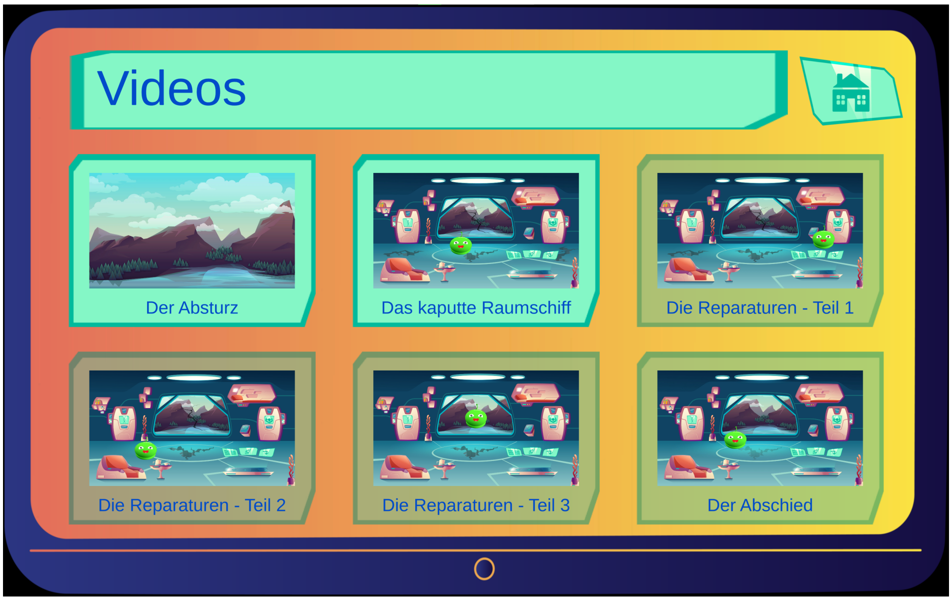


Figure A.1.: The video selection menu to re-watch story videos from child main menu. In this example only the first two video sequences are unlocked.

A.1.2. Parental Information and Imprint

Figure A.2.: Menu displaying parental information.

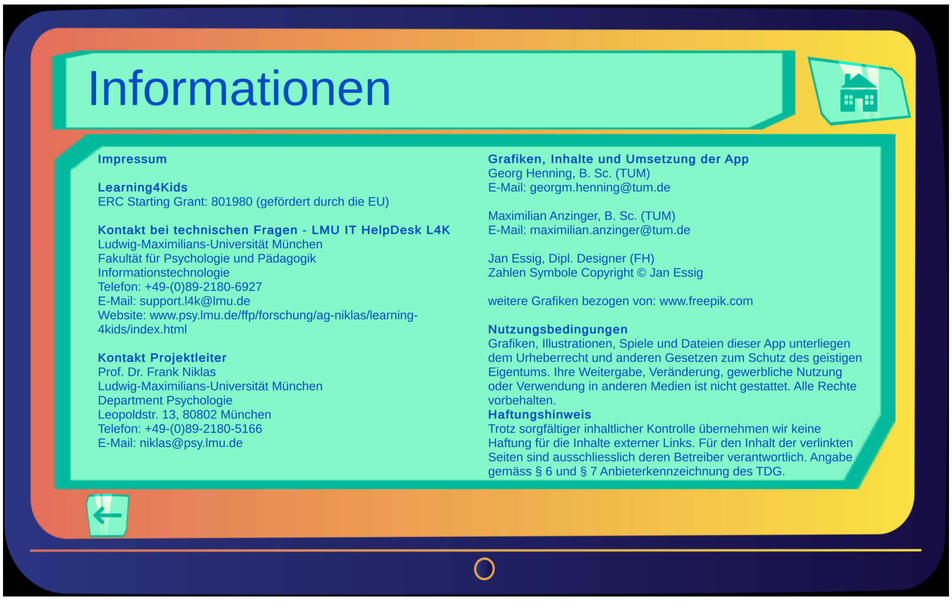
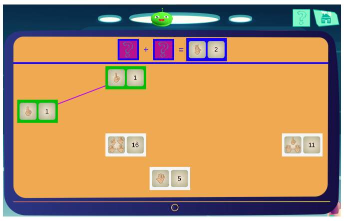


Figure A.3.: Menu displaying the imprint.

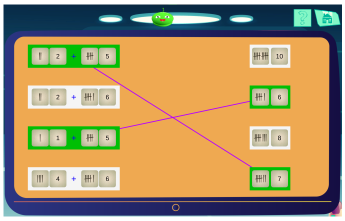
A.1.3. Code Input Menu

Figure A.4.: The Code Input Menu.

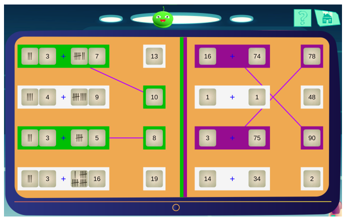
A.1.4. Mini Game Examples



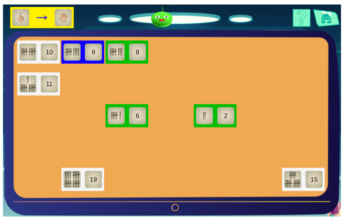
(a) Add mini game.



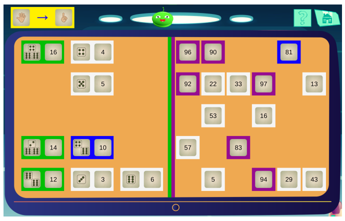
(b) Connect mini game.



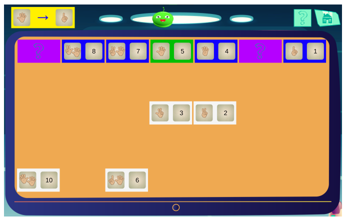
(c) ConnectVS mini game.



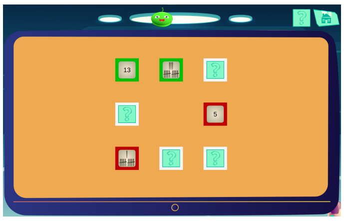
(d) Count mini game.



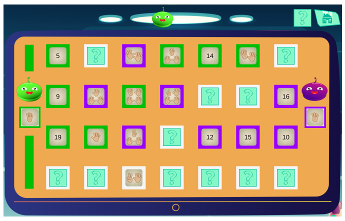
(e) CountVS mini game.



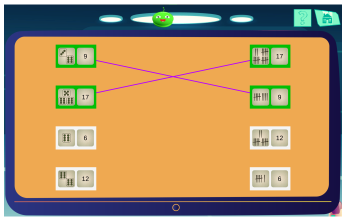
(f) Insert mini game.



(g) Memory mini game.



(h) MemoryVS mini game.



(i) Pairs mini game.

Figure A.5.: Examples for all featured mini games.

A.1.5. Number Representations

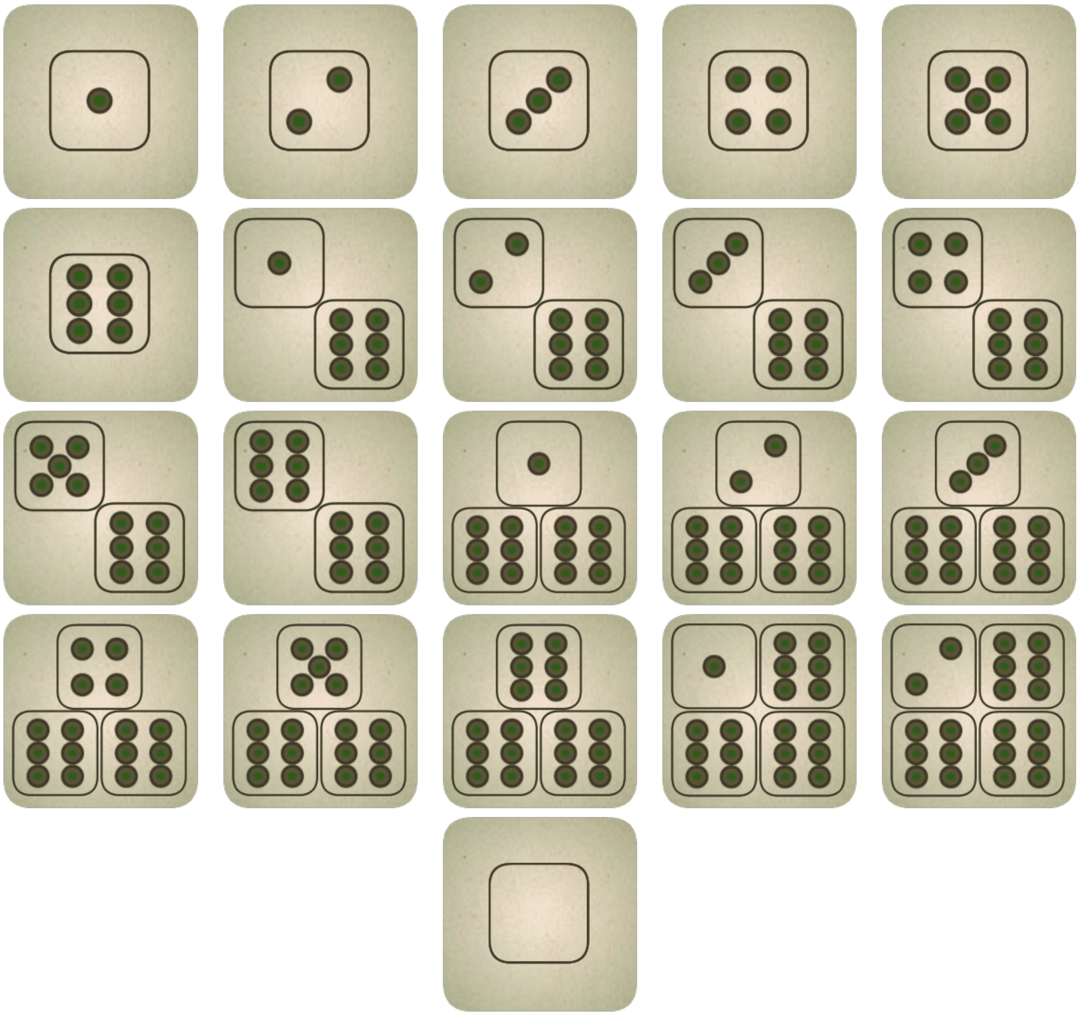


Figure A.6.: Dices number representations.

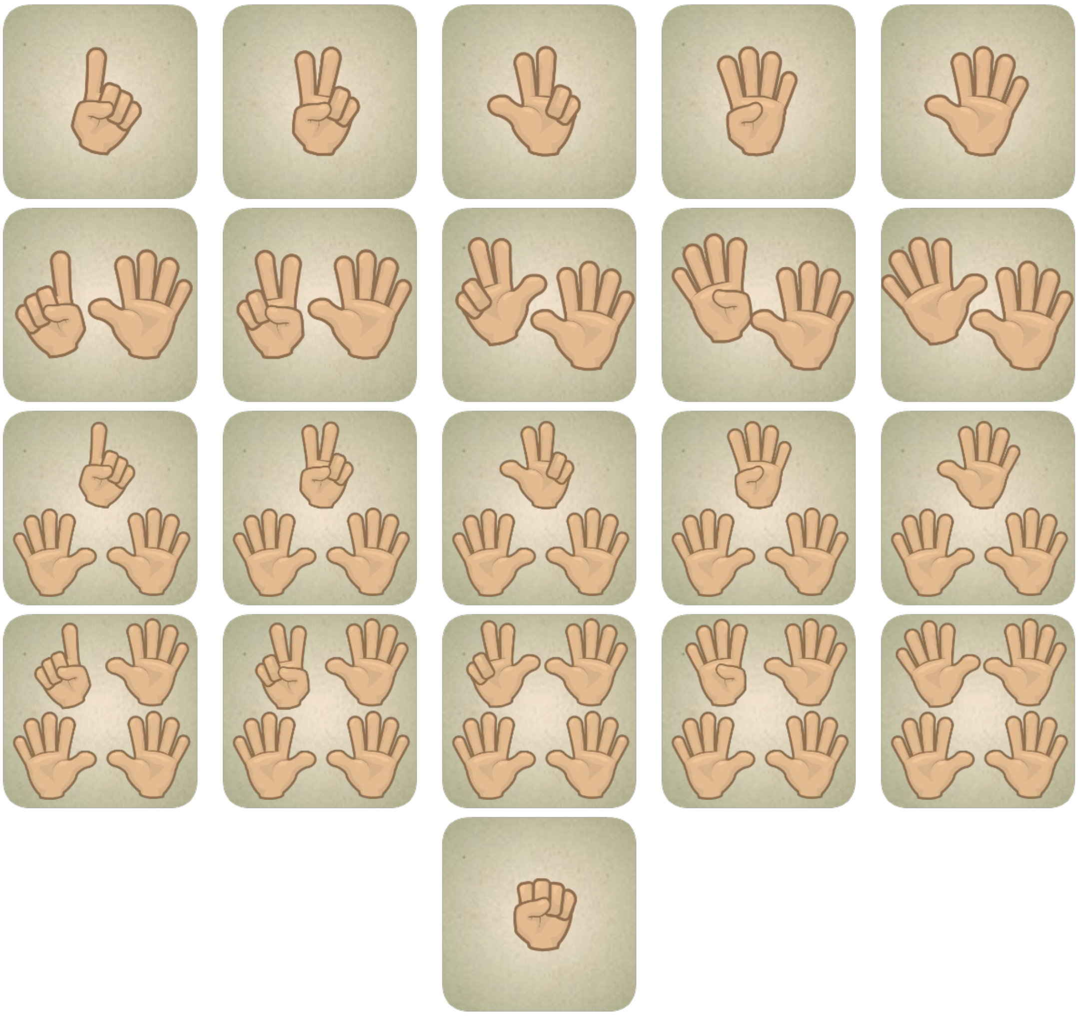


Figure A.7.: Fingers number representations.

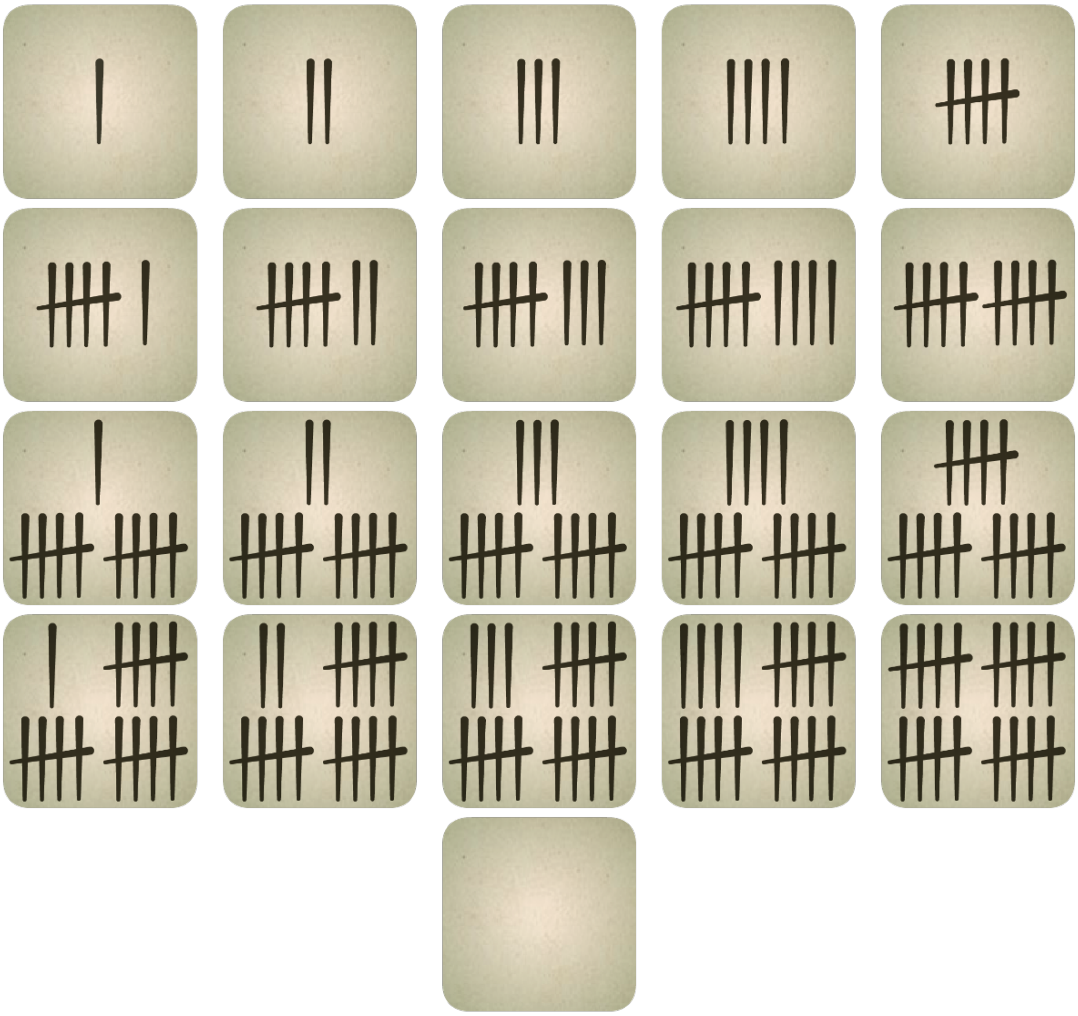
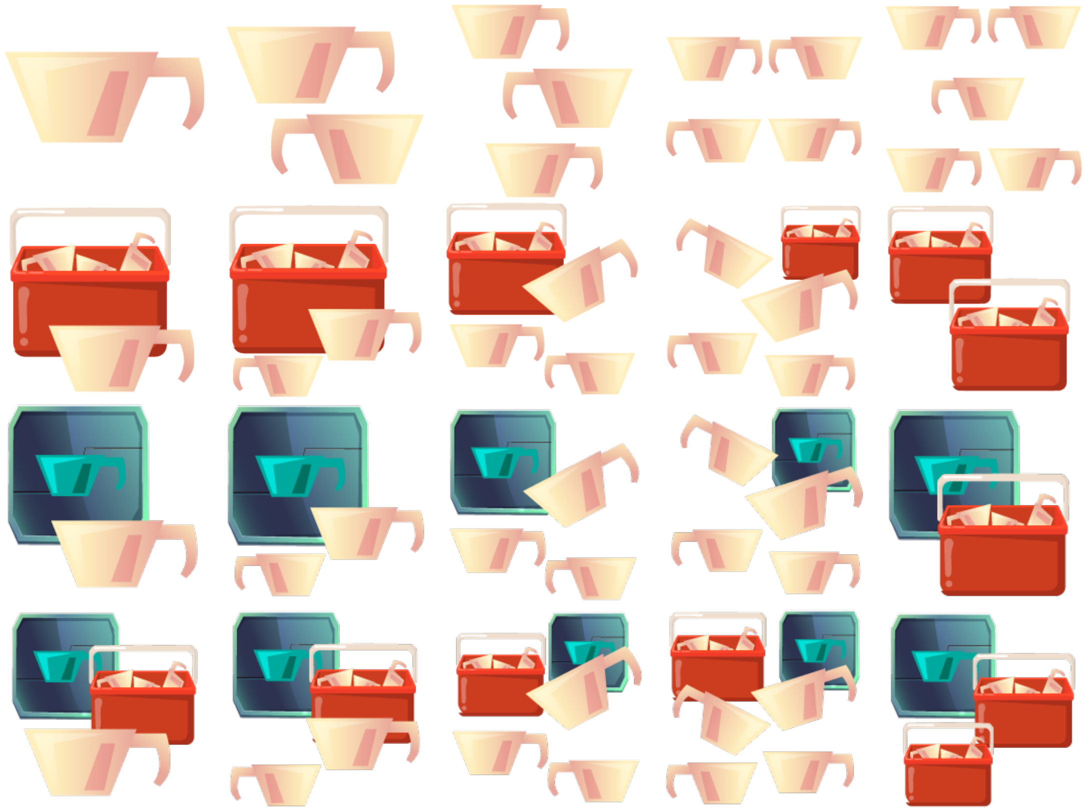


Figure A.8.: Lines number representations.



(a) Alternative representation for five.

(b) Alternative representation for ten.

Figure A.9.: Work in progress number representations with cups; not included in the final game.

A.1.6. Explanation Video Menu

Figure A.10.: Example for the explanation video menu with the pairs video.

A.1.7. Pause Menu

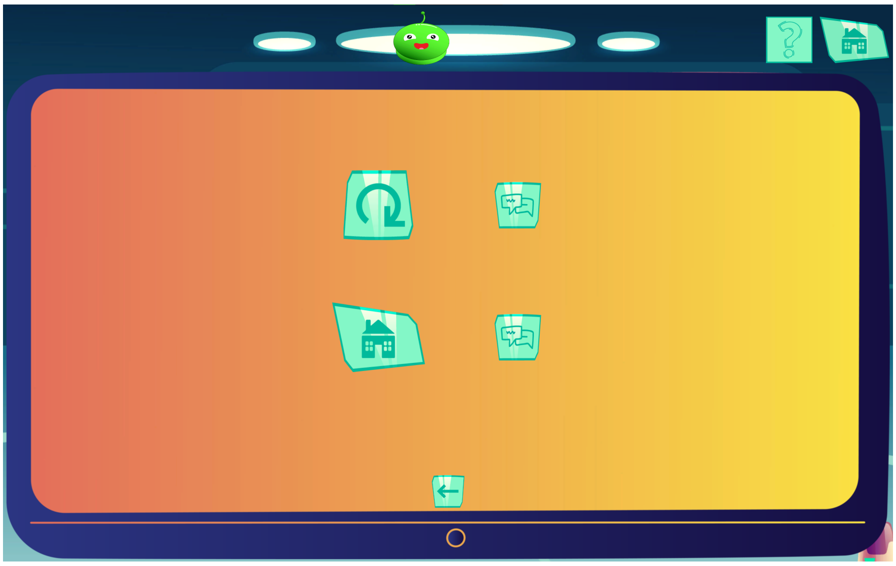


Figure A.11.: Example for the pause menu.

A.2. UFO Room Backgrounds

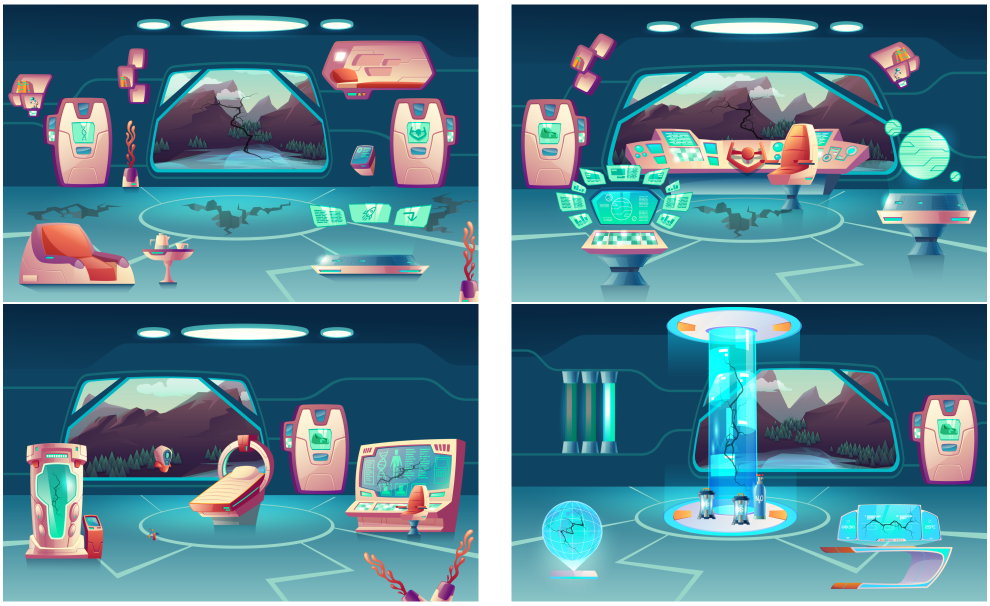


Figure A.12.: UFO room backgrounds at the begin of the story.

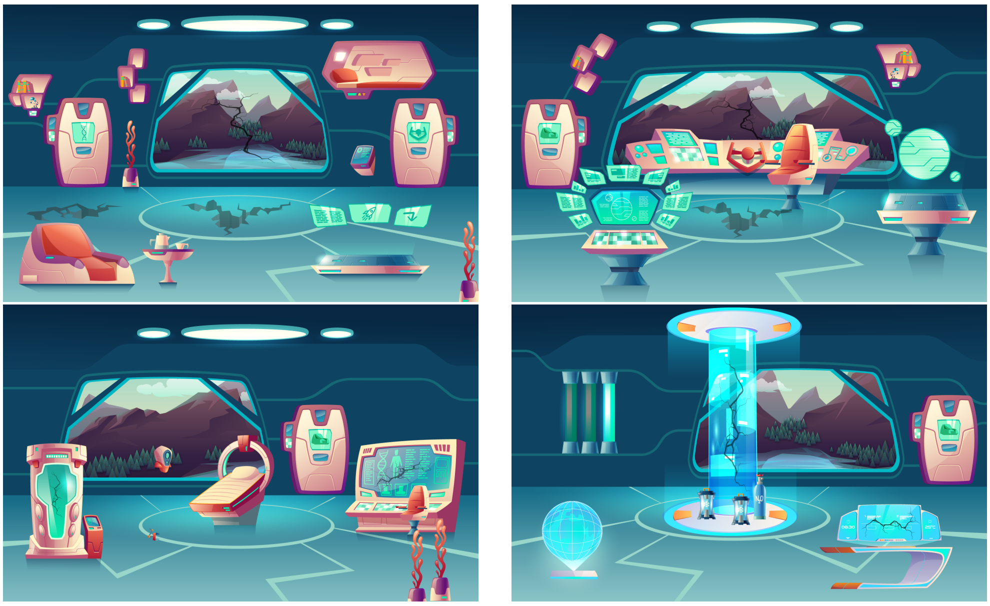


Figure A.13.: UFO room backgrounds after learning section 1.

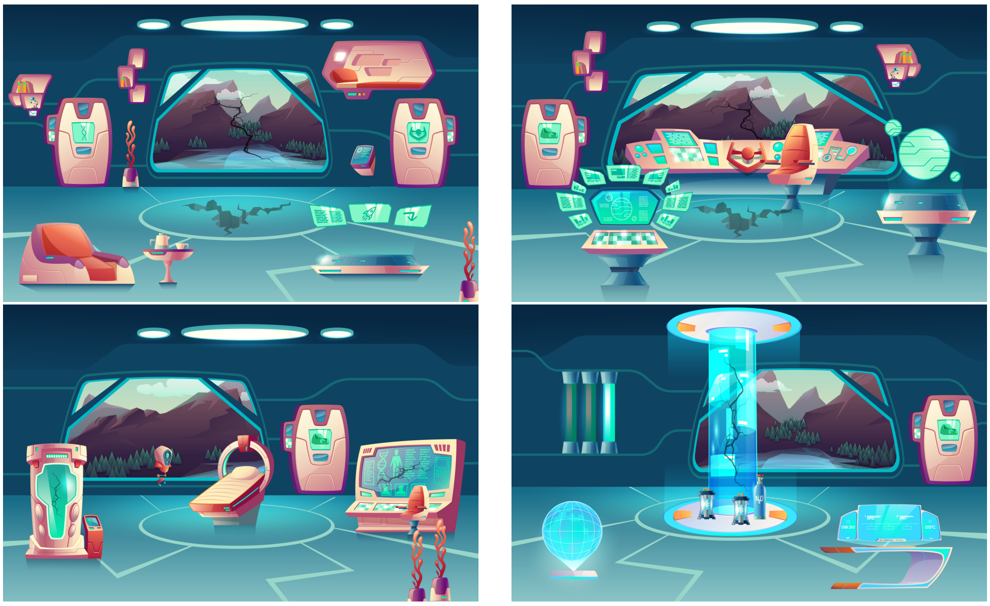


Figure A.14.: UFO room backgrounds after learning section 2.

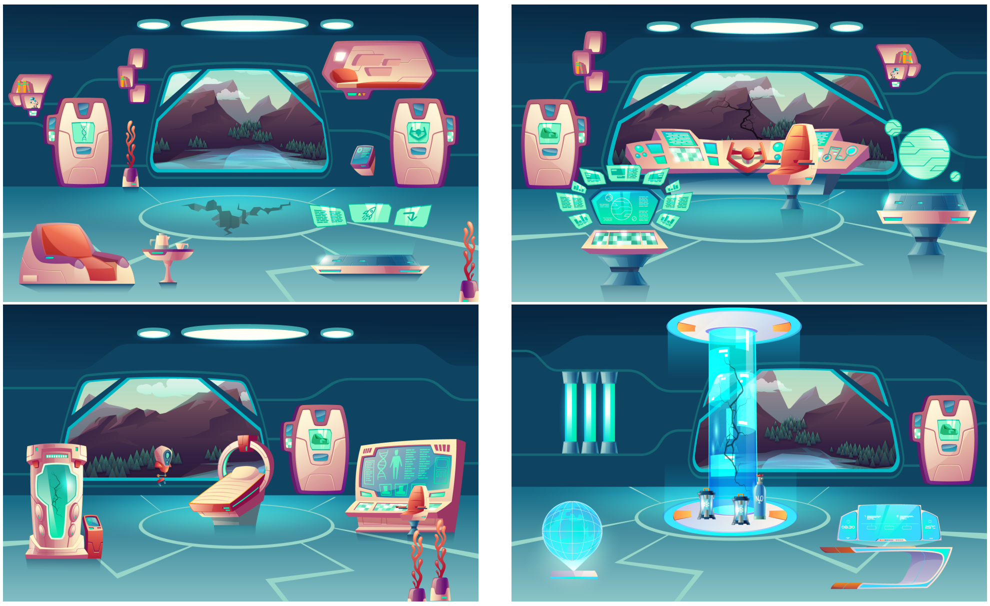


Figure A.15.: UFO room backgrounds after learning section 3.

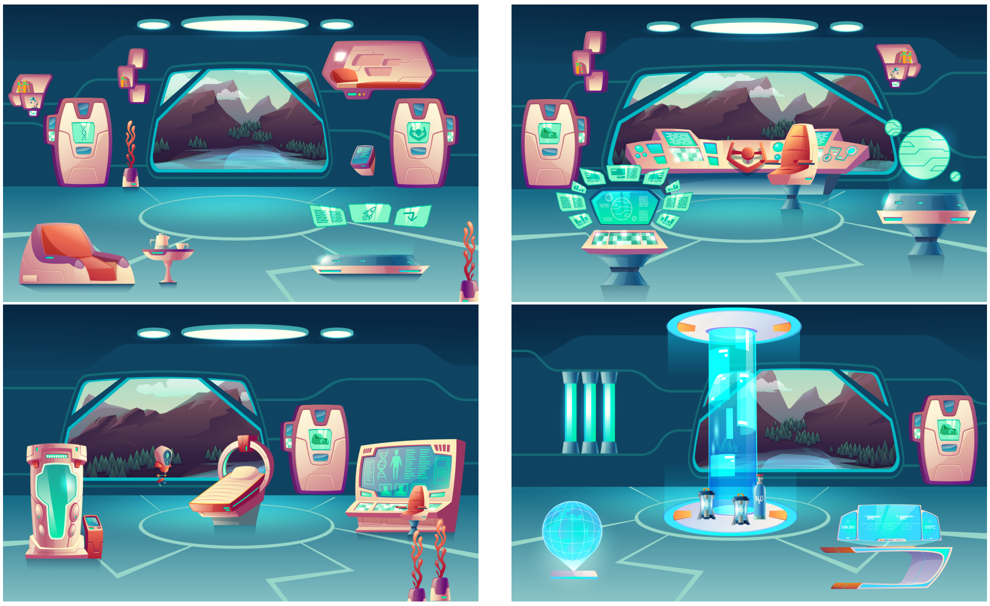


Figure A.16.: UFO room backgrounds after learning section 4.

A.3. Story Structure and Story Games

A.3.1. Story Structure

Figure A.17 and Figure A.18 show the dependencies between the mini game blocks in the story mode. The label of a block shows first the learning stage, second the room (**N**avigation, **L**aboratory, **E**ngine room), and third the block id. The arrows depict the dependencies between the blocks, i.e., the arrow from block 1.N.1 to 1.L.1 means that the games in block 1.L.1 will only be available after all games of block 1.N.1 had been completed. Subsection A.3.2 shows details of all story games, grouped by learning stage, and rooms.

A.3.2. Story Games Overview

This subsection contains tables with all mini games that have to be completed during the story of ″Blubs Abenteuer″. Each room has its own table for each learning stage.

The column ″Block″ refers to the block ids from Subsection A.3.1, ″Game type″ contains the mini game's type and additional information, i.e. ″<″/″>″ for increasing/decreasing or ″+″/″-″ for addition/subtraction tasks. Further, ″Numbers″ contains the involved numbers and ″Representation″ the used representation, where ″mixed″ refers to a randomly selected object representation (dice, lines or, hands). Table A.1 contains additional information about the ″Numbers″ column.

The last mini game of each block is a VS game and might be replaced by an equivalent single-player game, if no parent is available.

Table A.1.: Explanations for the ″Numbers″ column.

Table Content	Explanation
[x,y]	all numbers in the range from x to y
x out of [y,z]	x numbers randomly selected from range y to z
{x,y,z}	only numbers x,y and z
A,B+x	insert mini-game: from available numbers A are numbers B missing and the game contains x additional values
x (y pairs), z	add mini-game: connect y pairs to get target value x; z additional values are present
any	connect: the result of the tasks

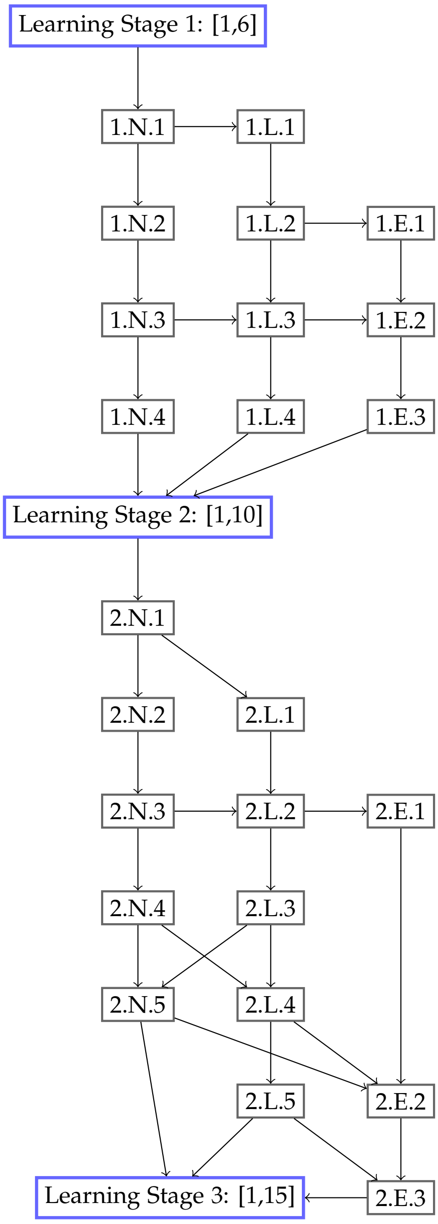


Figure A.17.: Game Block Structure of the Story Mode - Part 1.

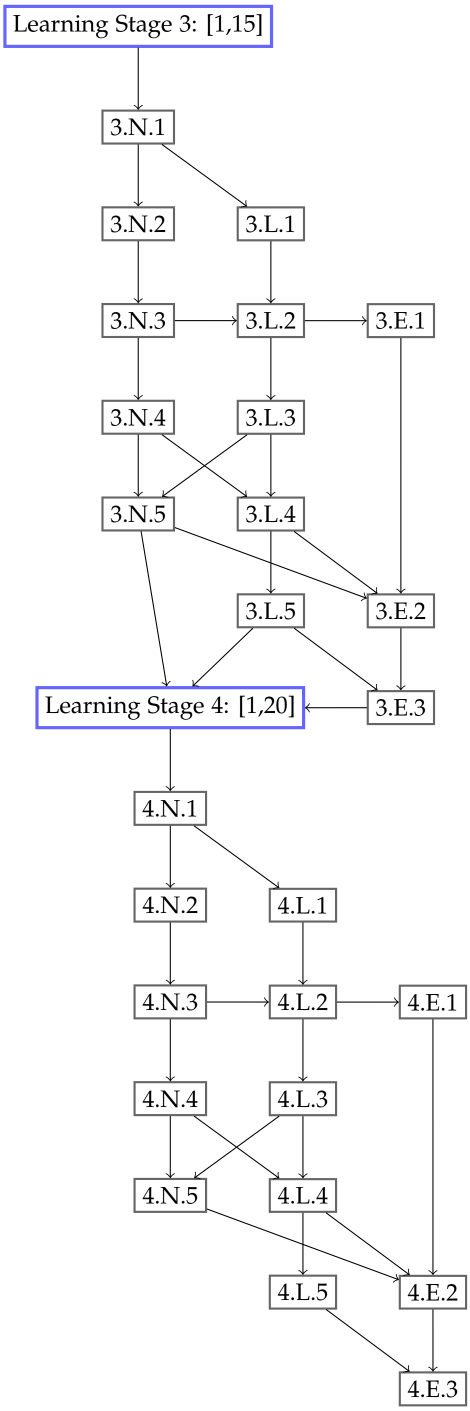


Figure A.18.: Game Block Structure of the Story Mode - Part 2.

Learning Stage 1

Table A.2.: Story Mini-Games, Learning Stage 1 - Navigation.

Block	Game type	Numbers	Representation
1	pairs	[1,6]	hands, lines
2	pairs	[1,6]	dices, hands+digits
2	pairs	[1,6]	lines+digits, hands
3	pairs	[1,6]	hands, digits
3	pairs	[1,6]	digits, lines
4	memory	4 out of [1,6]	mixed
4	memory	4 out of [1,6]	mixed+digits
5	memoryVS	4 out of [1,6]	mixed+digits

Table A.3.: Story Mini-Games, Learning Stage 1 - Laboratory.

Block	Game type	Numbers	Representation
1	count (<)	[1,6]	hands
2	insert (<)	[1,6], {2,4} + 0	dices
2	insert (>)	[1,6], {1,3,4} + 0	lines
3	count (>)	[1,6]	dices+digits
3	insert (<)	[1,6], {1,3,5,6} + 0	mixed+digits
4	count (<)	[1,6]	digits
4	insert (<)	[1,6], {1,3,4,6} + 0	digits
4	insert (>)	[1,6], {1,2,3,6} + 0	digits
5	countVS (<)	[1,6]	digits

Table A.4.: Story Mini-Games, Learning Stage 1 - Engine Room.

Block	Game type	Numbers	Representation
1	connect (+)	{2,3,6}	hands
1	add	6 (3 pairs), 0	dices
2	connect (+)	{2,4,5}	lines+digits
2	add	6 (3 pairs), 0	mixed+digits
3	connect (+)	{2,3,6}	digits
3	add	6 (3 pairs), 0	digits
3	connect (-)	[1,5]	digits
3	connectVS (+)	3 out of [2,6]	digits

Learning Stage 2

Table A.5.: Story Mini-Games, Learning Stage 2 - Navigation.

Block	Game type	Numbers	Representation
1	pairs	[6,10]	hands, lines
2	pairs	[6,10]	dices, hands+digits
2	pairs	[6,10]	lines+digits, hands
3	pairs	[6,10]	hands, digits
3	pairs	[6,10]	digits, lines
4	memory	4 out of [6,10]	mixed
4	memory	4 out of [6,10]	mixed+digits
5	pairs	5 out of [1,10]	mixed, mixed+digits
5	memory	4 out of [1,10]	mixed+digits
5	memoryVS	10 out of [1,10]	mixed+digits

Table A.6.: Story Mini-Games, Learning Stage 2 - Laboratory.

Block	Game type	Numbers	Representation
1	count (<)	[6,10]	hands
1	insert (<)	[6,10], {7,8} + 0	dices
1	insert (>)	[6,10], {7,9} + 0	lines
2	count (>)	[6,10]	dices+digits
2	insert (<)	[6,10], {6,9,10} + 0	mixed+digits
3	count (<)	[6,10]	digits
3	insert (<)	[6,10], {6,8,9}	digits
3	insert (>)	[6,10], {8,9,10}	digits
4	count (<)	[1,10]	mixed+digits
4	insert (<)	7 out of [1,10], 4 + 0	mixed+digits
5	count (>)	[1,10]	digits
5	insert (<)	10 out of [1,10], 5 + 0	digits
5	insert (<)	5 out of [1,10], 3 + 3	digits
5	countVS (>)	[1,10]	digits

Table A.7.: Story Mini-Games, Learning Stage 2 - Engine Room.

Block	Game type	Numbers	Representation
1	connect (+)	[6,10]	hands
1	add	10 (5 pairs), 0	dices
1	connect (-)	{1,3,5,8}	lines
2	connect (+)	{3,7,9,10}	lines+digits
2	add (+)	9 (4 pairs), 0	mixed+digits
2	connect (-)	{2,4,6,9}	mixed+digits
3	connect (+)	5 out of [2,10]	digits
3	add (+)	10 (5 pairs), 3	digits
3	connect (-)	5 out of [1,9]	digits
3	connectVS (+)	4 out of [2,10]	digits

Learning Stage 3

Table A.8.: Story Mini-Games, Learning Stage 3 - Navigation.

Block	Game type	Numbers	Representation
1	pairs	[10,15]	hands, lines
2	pairs	[10,15]	dices, hands+digits
2	pairs	[10,15]	lines+digits, hands
3	pairs	[10,15]	hands, digits
3	pairs	[10,15]	digits, lines
4	memory	4 out of [10,15]	mixed
4	memory	4 out of [10,15]	mixed+digits
5	pairs	6 out of [1,15]	mixed, mixed+digits
5	memory	10 out of [1,15]	mixed+digits
5	memoryVS	10 out of [1,15]	mixed+digits

Table A.9.: Story Mini-Games, Learning Stage 3 - Laboratory.

Block	Game type	Numbers	Representation
1	count (<)	[10,15]	hands
1	insert (<)	[10,15], {13,14} + 0	dices
1	insert (>)	[10,15], {11,12,14} + 0	lines
2	count (>)	[10,15]	dices+digits
2	insert (<)	[10,15], {10,11,12,15} + 0	mixed+digits
3	count (<)	[10,15]	digits
3	insert (<)	[10,15], {10,12,13}	digits
3	insert (>)	[10,15], {12,13,14}	digits
4	count (<)	[1,15]	mixed+digits
4	insert (<)	7 out of [1,15], 4 + 0	mixed+digits
5	count (>)	10 out of [1,15]	digits
5	insert (<)	10 out of [1,15], 5 + 0	digits
5	insert (<)	5 out of [1,15], 3 + 3, 3	digits
5	countVS (>)	[1,15]	digits

Table A.10.: Story Mini-Games, Learning Stage 3 - Engine Room.

Block	Game type	Numbers	Representation
1	connect (+)	[11,15]	hands
1	add	15 (7 pairs), 0	dices
1	connect (-)	{3,5,8,11}	lines
2	connect (+)	{5,8,12,14}	lines+digits
2	add (+)	14 (7 pairs), 0	mixed+digits
2	connect (-)	{2,4,6,9,11}	mixed+digits
3	connect (+)	5 out of [2,15]	digits
3	add (+)	15 (5 pairs), 3	digits
3	connect (-)	5 out of [1,14]	digits
3	connectVS (+)	4 out of [2,15]	digits

Learning Stage 4

Table A.11.: Story Mini-Games, Learning Stage 4 - Navigation.

Block	Game type	Numbers	Representation
1	pairs	[15,20]	hands, lines
2	pairs	[15,20]	dices, hands+digits
2	pairs	[15,20]	lines+digits, hands
3	pairs	[15,20]	hands, digits
3	pairs	[15,20]	digits, lines
4	memory	4 out of [15,20]	mixed
4	memory	4 out of [15,20]	mixed+digits
5	pairs	6 out of [1,20]	mixed, mixed+digits
5	memory	10 out of [1,20]	mixed+digits
5	memoryVS	14 out of [1,20]	mixed+digits

Table A.12.: Story Mini-Games, Learning Stage 4 - Laboratory.

Block	Game type	Numbers	Representation
1	count (<)	[15,20]	hands
1	insert (<)	[15,20], {16,19} + 0	dices
1	insert (>)	[15,20], {15,16,18} + 0	lines
2	count (>)	[15,20]	dices+digits
2	insert (<)	[15,20], {15,16,17,20} + 0	mixed+digits
3	count (<)	[15,20]	digits
3	insert (<)	[15,20], {15,17,18}	digits
3	insert (>)	[15,20], {15,18,19}	digits
4	count (<)	[1,20]	mixed+digits
4	insert (<)	7 out of [1,20], 4 + 0	mixed+digits
5	count (>)	15 out of [1,20]	digits
5	insert (<)	10 out of [1,20], 5 + 0	digits
5	insert (<)	5 out of [1,20], 3 + 3, 3	digits
5	countVS (>)	[1,20]	digits

Table A.13.: Story Mini-Games, Learning Stage 3 - Engine Room.

Block	Game type	Numbers	Representation
1	connect (+)	[16,20]	hands
1	add	20 (10 pairs), 0	dices
1	connect (-)	{3,10,13,16}	lines
2	connect (+)	{10,13,17,19}	lines+digits
2	add (+)	19 (9 pairs), 2	mixed+digits
2	connect (-)	{2,6,11,14,17}	mixed+digits
3	connect (+)	5 out of [2,20]	digits
3	add (+)	20 (5 pairs), 3	digits
3	connect (-)	5 out of [1,19]	digits
3	connectVS (+)	4 out of [2,20]	digits

Abbreviations

ARCS Attention Relevance Confidence Satisfaction model

BA "Blubs Abenteuer" (engl. Blub's Adventure)

CLT Cognitive Load Theory

HNE Home Numeracy Environment

IDP interdisciplinary project

VS two-player/versus

List of Figures

List of Tables

Bibliography

[1] N. Ahire, R. Awale, S. Patnaik, and A. Wagh, "A comprehensive review of machine learning approaches for dyslexia diagnosis," *Multimedia Tools and Applications*, vol. 82, no. 9, pp. 13 557–13 577, 2023, ISSN: 1380-7501.

[2] G. R. Lyon, S. E. Shaywitz, and B. A. Shaywitz, "A definition of dyslexia," *Annals of dyslexia*, pp. 1–14, 2003, ISSN: 0736-9387.

[3] S. E. Shaywitz, "Dyslexia," *New England Journal of Medicine*, vol. 338, no. 5, pp. 307–312, 1998, ISSN: 0028-4793.

[4] R. S. Shalev and V. Gross-Tsur, "Developmental dyscalculia," *Pediatric neurology*, vol. 24, no. 5, pp. 337–342, 2001, ISSN: 0887-8994.

[5] L. Kosc, "Developmental dyscalculia," *Journal of learning disabilities*, vol. 7, no. 3, pp. 164–177, 1974, ISSN: 0022-2194.

[6] B. Butterworth, S. Varma, and D. Laurillard, "Dyscalculia: From brain to education," *science*, vol. 332, no. 6033, pp. 1049–1053, 2011, ISSN: 0036-8075.

[7] S. Haberstroh and G. Schulte-Körne, "The diagnosis and treatment of dyscalculia," *Deutsches Ärzteblatt International*, vol. 116, no. 7, p. 107, 2019.

[8] World Health Organization (WHO), *Icd-11 : International classification of diseases : Eleventh revision*, 2019.

[9] World Health Organization (WHO), *Icd-10 : International statistical classification of diseases and related health problems : Tenth revision*, 2004.

[10] G. Schulte-Körne, "Verpasste chancen: Die neuen diagnostischen leitlinien zur lese-, rechtschreib- und rechenstörung der icd-11," *Zeitschrift für Kinder- und Jugendpsychiatrie und Psychotherapie*, vol. 49, no. 6, pp. 463–467, 2021, PMID: 33666495. DOI: `10.1024/1422-4917/a000791`. eprint: `https://doi.org/10.1024/1422-4917/a000791`.

[11] C. Jacobs and F. Petermann, "Dyskalkulie–forschungsstand und perspektiven," *Kindheit und Entwicklung*, vol. 12, no. 4, pp. 197–211, 2003.

[12] J. J. Heckman, "Skill formation and the economics of investing in disadvantaged children," *Science*, vol. 312, no. 5782, pp. 1900–1902, 2006.

[13] K. Magnuson and G. J. Duncan, "Can early childhood interventions decrease inequality of economic opportunity?" *RSF: The Russell Sage Foundation Journal of the Social Sciences*, vol. 2, no. 2, pp. 123–141, 2016, ISSN: 2377-8253. DOI: 10.7758/RSF.2016.2.2.05. eprint: https://www.rsfjournal.org/content/2/2/123.full.pdf.

[14] J. J. Heckman, "The economics of inequality: The value of early childhood education.," *American Educator*, vol. 35, no. 1, p. 31, 2011.

[15] K. Pittman, J. Tolman, and N. Yohalem, "Developing a comprehensive agenda for the out-of-school hours: Lessons and challenges across cities," in *Organized Activities As Contexts of Development*, Psychology Press, 2005, pp. 387–410.

[16] LIFE Center. "The life center's lifelong and lifewide diagram." (2005), [Online]. Available: http://life-slc.org/about/citationdetails.html (visited on 09/09/2022).

[17] T. M. Akiva, "The psychology of youth participation in organized activities," Ph.D. dissertation, University of Michigan, 2012.

[18] F. Niklas and W. Schneider, "Casting the die before the die is cast: The importance of the home numeracy environment for preschool children," *European Journal of Psychology of Education*, vol. 29, pp. 327–345, 2014, ISSN: 0256-2928.

[19] M. Arora, L. M. Goyal, N. Chintalapudi, and M. Mittal, "Factors affecting digital education during covid-19: A statistical modeling approach," in *2020 5th International Conference on Computing, Communication and Security (ICCCS)*, IEEE, pp. 1–5, ISBN: 1728191807.

[20] L. K. Fryer and H. N. Bovee, "Supporting students' motivation for e-learning: Teachers matter on and offline," *Internet and Higher Education*, vol. 30, pp. 21–29, 2016, ISSN: 1096-7516. DOI: 10.1016/j.iheduc.2016.03.003.

[21] J. M. Keller, "First principles of motivation to learn and e(3)-learning," *Distance Education*, vol. 29, no. 2, pp. 175–185, 2008, ISSN: 0158-7919. DOI: 10.1080/01587910802154970.

[22] N. L. Ray, "Motivation in education," 1992.

[23] S. Schukajlow, K. Rakoczy, and R. Pekrun, "Emotions and motivation in mathematics education: Where we are today and where we need to go," *ZDM–Mathematics Education*, pp. 1–19, 2023, ISSN: 1863-9690.

[24] L. K. Fryer, H. N. Bovee, and K. Nakao, "E-learning: Reasons students in language learning courses don't want to," *Computers & Education*, vol. 74, pp. 26–36, 2014, ISSN: 0360-1315. DOI: 10.1016/j.compedu.2014.01.008.

[25] J. M. Keller, "An integrative theory of motivation, volition, and performance," *Technology, Instruction, Cognition, and Learning*, vol. 6, no. 2, pp. 79–104, 2008.

[26] J. Kuhl, "Action control: The maintenance of motivational states," in *Motivation, intention, and volition*, Springer, pp. 279–291, ISBN: 3642709699.

[27] B. J. Zimmerman, "Academic studing and the development of personal skill: A self-regulatory perspective," *Educational psychologist*, vol. 33, no. 2-3, pp. 73–86, 1998, ISSN: 0046-1520.

[28] L. Corno, "Volitional aspects of self-regulated learning," in *Self-regulated learning and academic achievement*. Routledge, 2013, pp. 179–212, ISBN: 141060103X.

[29] S. Kleitman, L. Stankov, C. M. Allwood, S. Young, and K. K. L. Mak, "Metacognitive self-confidence in school-aged children," in *Self-directed learning oriented assessments in the Asia-Pacific*, Springer, 2012, pp. 139–153.

[30] N. L. Ennen, E. Stark, and A. Lassiter, "The importance of trust for satisfaction, motivation, and academic performance in student learning groups," *Social Psychology of education*, vol. 18, pp. 615–633, 2015, ISSN: 1381-2890.

[31] Y. D. Wang, "Building student trust in online learning environments," *Distance Education*, vol. 35, no. 3, pp. 345–359, 2014, ISSN: 0158-7919. DOI: `10.1080/01587919.2015.955267`.

[32] M. A. Uppal, S. Ali, and S. R. Gulliver, "Factors determining e-learning service quality," *British Journal of Educational Technology*, vol. 49, no. 3, pp. 412–426, 2018, ISSN: 0007-1013. DOI: `10.1111/bjet.12552`.

[33] M. Anwar and J. Greer, "Facilitating trust in privacy-preserving e-learning environments," *IEEE Transactions on Learning Technologies*, vol. 5, no. 1, pp. 62–73, 2012, ISSN: 1939-1382. DOI: `10.1109/TLT.2011.23`.

[34] J. Song and F. " Zahedi, "Trust in health infomediaries," *Decision Support Systems*, vol. 43, no. 2, pp. 390–407, 2007, ISSN: 0167-9236. DOI: `https://doi.org/10.1016/j.dss.2006.11.011`.

[35] G. Bansal and F. Zahedi, "The moderating influence of privacy concern on the efficacy of privacy assurance mechanisms for building trust: A multiple-context investigation," *ICIS 2008 Proceedings*, p. 7, 2008.

[36] P. T. Jaeger and X. Bo, "Developing online community accessibility guidelines for persons with disabilities and older adults," *Journal of Disability Policy Studies*, vol. 20, no. 1, pp. 55–63, 2008, ISSN: 1044-2073. DOI: `10.1177/1044207308325997`.

[37] A. I. Nicolaou and D. H. McKnight, "Perceived information quality in data exchanges: Effects on risk, trust, and intention to use," *Information Systems Research*, vol. 17, no. 4, pp. 332–351, 2006. DOI: `10.1287/isre.1060.0103`.

[38] A. Curzon-Hobson, "A pedagogy of trust in higher learning," *Teaching in Higher Education*, vol. 7, no. 3, pp. 265–276, 2002, ISSN: 1356-2517. DOI: 10.1080/13562510220144770.

[39] A. G. Wooten and J. C. McCroskey, "Student trust of teacher as a function of socio-communicative style of teacher and socio-communicative orientation of student," *Communication Research Reports*, vol. 13, no. 1, pp. 94–100, 1996, ISSN: 0882-4096. DOI: 10.1080/08824099609362075.

[40] F. Akhter, M. C. Buzzi, M. Buzzi, and B. Leporini, "Conceptual framework: How to engineer online trust for disabled users," in *2009 IEEE/WIC/ACM International Joint Conference on Web Intelligence and Intelligent Agent Technology*, vol. 3, IEEE, pp. 614–617, ISBN: 0769538010.

[41] E.-K. Khalil, K. Larry, X. Yuefei, and Y. George, "Privacy and security in e-learning," *International Journal of Distance Education Technologies (IJDET)*, vol. 1, no. 4, pp. 1–19, 2003, ISSN: 1539-3100. DOI: 10.4018/jdet.2003100101.

[42] R. Raitman, L. Ngo, N. Augar, and W. Zhou, "Security in the online e-learning environment," in *Fifth IEEE International Conference on Advanced Learning Technologies (ICALT'05)*, IEEE, pp. 702–706, ISBN: 0769523382.

[43] R. E. Mayer, "Using multimedia for e-learning," *Journal of Computer Assisted Learning*, vol. 33, no. 5, pp. 403–423, 2017, ISSN: 0266-4909. DOI: 10.1111/jcal.12197.

[44] A. Paivio, *Mental representations: A dual coding approach*. Oxford University Press, 1990, ISBN: 0195362004.

[45] A. D. Baddeley, *Human memory: Theory and practice*. psychology press, 1997, ISBN: 0863774318.

[46] J. Sweller, P. Ayres, and S. Kalyuga, *Cognitive Load Theory* (Explorations in the Learning Sciences, Instructional Systems and Performance Technologies). New York, NY: Springer, 2011, vol. 1, p. 274, ISBN: 978-1-4419-8125-7. DOI: 10.1007/978-1-4419-8126-4.

[47] R. E. Mayer, *Multimedia Learning*, 3rd ed. Cambridge: Cambridge University Press, 2020, ISBN: 9781107187504. DOI: DOI:10.1017/9781316941355.

[48] M. C. Wittrock, "Generative processes of comprehension," *Educational Psychologist*, vol. 24, no. 4, pp. 345–376, 1989, ISSN: 0046-1520. DOI: 10.1207/s15326985ep2404_2.

[49] F. Paas, A. Renkl, and J. Sweller, "Cognitive load theory and instructional design: Recent developments," *Educational psychologist*, vol. 38, no. 1, pp. 1–4, 2003, ISSN: 0046-1520.

[50] J. L. Plass, R. Moreno, and R. Brünken, "Cognitive load theory," 2010, ISSN: 0521860237.

[51] J. Sweller, "Element interactivity and intrinsic, extraneous, and germane cognitive load," *Educational psychology review*, vol. 22, pp. 123–138, 2010, ISSN: 1040-726X.

[52] J. Sweller, J. J. G. van Merrienboer, and F. G. W. C. Paas, "Cognitive architecture and instructional design," *Educational Psychology Review*, vol. 10, no. 3, pp. 251–296, 1998, ISSN: 1573-336X. DOI: `10.1023/A:1022193728205`.

[53] O. O. Adesope and J. C. Nesbit, "Verbal redundancy in multimedia learning environments: A meta-analysis," *Journal of Educational Psychology*, vol. 104, no. 1, p. 250, 2012, ISSN: 1939-2176.

[54] R. Moreno and R. E. Mayer, "Verbal redundancy in multimedia learning: When reading helps listening," *Journal of educational psychology*, vol. 94, no. 1, p. 156, 2002, ISSN: 1939-2176.

[55] C. L. Yue, E. L. Bjork, and R. A. Bjork, "Reducing verbal redundancy in multimedia learning: An undesired desirable difficulty?" *Journal of Educational Psychology*, vol. 105, no. 2, p. 266, 2013, ISSN: 1939-2176.

[56] B. S. Hasler, B. Kersten, and J. Sweller, "Learner control, cognitive load and instructional animation," *Applied Cognitive Psychology: The Official Journal of the Society for Applied Research in Memory and Cognition*, vol. 21, no. 6, pp. 713–729, 2007, ISSN: 0888-4080.

[57] K. D. Stiller, A. Freitag, P. Zinnbauer, and C. Freitag, "How pacing of multimedia instructions can influence modality effects: A case of superiority of visual texts," *Australasian Journal of Educational Technology*, vol. 25, no. 2, 2009, ISSN: 1449-5554.

[58] H. Kuckeland, L. Pongrac, K. Sauerwein, and K. Schneider, "Auswahlkriterien von lernpausen," *Unterricht Pflege*, vol. 20, no. 3, pp. 7–9, 2015.

[59] Unity Technologies. "Unity software additional terms." (2022), [Online]. Available: `https://unity.com/legal/terms-of-service/software` (visited on 09/09/2022).

[60] M. Anzinger and G. Henning. "Blubs Abenteuer - GitHub Repository." (2023), [Online]. Available: `https://github.com/Mauri2070/Blubs-Abenteuer` (visited on 03/11/2023).

[61] M. Anzinger and G. Henning. "Blubs Abenteuer - Full Walkthrough." (2022), [Online]. Available: `https://www.youtube.com/playlist?list=PLx037SnxNn8neuPhdR_PWuka9DNtJm4iR` (visited on 04/25/2023).

[62] Chair of Education and Educational Psychology at the University of Munich (LMU). "Learning4kids." (2023), [Online]. Available: https://www.psy.lmu.de/ffp_en/research/ag-fischer_neu_/current-projects/learning-4kids/index.html (visited on 03/31/2023).

[63] M. Anzinger and G. Henning. "Blubs Abenteuer - Story Videos." (2023), [Online]. Available: https://www.youtube.com/playlist?list=PLRbyKwnucw2zjWFDyQ9IbJY6NufNAZCR3 (visited on 04/25/2023).

[64] K. Hirsh-Pasek, J. M. Zosh, R. M. Golinkoff, J. H. Gray, M. B. Robb, and J. Kaufman, "Putting education in "educational" apps: Lessons from the science of learning," *Psychological Science in the Public Interest*, vol. 16, no. 1, pp. 3–34, 2015, ISSN: 1529-1006.