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Horst – The Teaching Frog: Learning the Anatomy of a Frog Using Tangible AR

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Figure 1: During the dissection, learners can extract individual markers, i.e., organs and learn about their functions.

ABSTRACT

Learning environments targeting Augmented Reality (AR) visualize complex facts, can increase a learner's motivation, and allow for the application of learning contents. When using tangible user interfaces, the learning process receives a physical aspect improving the overall intuitive use. We present a tangible AR system targeting the learning of a frog's anatomy. The learning environment is based on a plushfrog containing removable markers. Detecting the markers, replaces them with 3D models of the organs. By extracting individual organs, learners can inspect them up close and learn more about their functions. Our AR frog further includes a quiz for a self-assessment of the learning progress and a gamification system to raise the overall motivation.

CCS CONCEPTS

• **Applied computing** → **Education**; • **Human-centered computing**;

KEYWORDS

augmented reality, education, serious games, gamification, tangible user interfaces

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1 INTRODUCTION

One method to teach the biology of vertebrates includes the dissection of a frog. Since this approach causes animal suffering and death as well as a potential desensitization of students, it is more than questionable [6].

An alternative to this approach is the utilization of digital simulations [14], e.g., *Digital Frog* [13], *Froggipedia* [20], and *Frog Dissection* [9]. These simulations allow for a step-by-step dissection of a frog while simultaneously providing further information about the frog's organs. This even leads to a more effective learning [31]. However, these applications leave out a spatial and direct visualization that is possible with Augmented Reality (AR) [12].

Using AR for educational purposes can lead to an increased motivation, a gain of experience with the direct application of the learning contents, and a higher task performance [4]. In combination with tangible user interfaces, the learning process further receives a physical aspect improving the overall intuitive use [7]. The motivating aspects can further be improved when following a gamified approach [22, 23]. Therefore, by providing a gamified tangible AR learning environment, students might learn about the anatomy of vertebrates in a highly motivated, effective, and ethical way.

Contribution

In this paper, we present the design and the realization of an AR learning environment targeting the learning of a frog's anatomy: *Horst – The Teaching Frog*. The learning environment is based on a plushfrog containing removable markers, thus building on the advantages of tangible user interfaces for learning. Learners can dissect the frog by opening a zipper at the frog's belly to reveal markers representing the organs. Detecting the markers, replaces them with 3D models of the organs. By extracting individual organs, learners can inspect them up close and learn more about their functions. Our AR frog further includes a quiz for a self-assessment of the learning progress and a gamification system, e.g., achievements and highscores, to raise the overall motivation.

2 RELATED WORK

Learning new knowledge is a challenging task that requires a high degree of motivation, discipline, and hard work [30]. By embedding the learning process in a gamified learning environment, the learning process becomes an engaging, vivid, and inspiring experience [21]. Gamified learning environments can either be *serious games* [10] or non-gaming learning applications enhanced by *gamification* [26]. Serious games feature an educational aspect and are not solely developed for entertainment [1]. Gamification refers to the implementation of game design elements, e.g., highscores and achievements, in non-gaming contexts to increase a user's motivation towards using the application [11]. The learning, i.e., the application and demonstration of the learning contents, is achieved by mapping the learning contents to a gamified learning environment's game mechanics or core interactions [24].

2.1 Augmented Reality

AR three-dimensionally integrates virtual elements into the real world that are interactive in real time [3]. Using AR applications in an educational context can lead to an increased motivation, improvements with respect to interaction and collaboration, and gaining experience with the direct application of the learning contents [4]. Thus far, learning applications targeting AR are used in almost any kind of area, but mostly focus STEM related topics [4]. For instance, *Mathland* demonstrates the mathematics behind the Newtonian physics and allows users to modify the physical laws [19].

AR elements can be manipulated using a tangible user interface [7]. A tangible user interface connects digital information with real world objects, i.e., using the objects as input and output devices [17]. Tangible AR interfaces register virtual objects to real world objects, thus allowing for a manipulation of a virtual object by manipulating its physical counterpart [7]. This approach renders an AR system very intuitive [7] and especially suits the visualization of 3D models [5]. With respect to learning, tangible AR can reduce cognitive load, intensify work on learning material, improve usability, support mental skills and collaboration [2].

2.2 Designing AR Learning Applications

Several theories have been formulated that approach to define the process of learning, e.g., the theories of behaviorism, cognitivism, and constructivism [18]. These theories can act as guidelines for the pedagogical design of AR learning applications and serious games.

The learning theory of *behaviorism* defines an individual learning process as a black box and focuses feedback. Behavioristic learning takes place through positive or negative reinforcement by the environment and by a repetition of the learning contents [18, 28]. In the context of game design, behavioristic learning can be achieved by implementing rewards, punishments, and an episodic gameplay. Reward game mechanics, e.g., highscores, experience points, and loot upon defeating an enemy, provide a player with positive feedback about their actions. Punishments, e.g., reducing the durability of a player's equipment or simulating an injury slowing down a player, give players negative feedback. An episodic gameplay is achieved by designing short levels of which each represents an individual challenge that can be repeated quickly.

In contrast to behavioristic learning, *cognitivism* defines learning as a process that leads to the development of internal cognitive structures [18, 28]. Following the theory of cognitivism, the learning process can be guided by the provision of a specific problem that motivates players to tackle the learning content, e.g., a background story introducing the player's goals. The learning process can also be controlled by providing a tutorial that is followed by subsequent challenges leading to further applications of the learning content. The underlying principles and the results of a player's actions need to be explicitly presented in an audiovisual way to support the learning process. Finally, the difficulty of the gameplay has to be adjusted to match the learning effect and to take gained experience into account.

According to the learning theory of *constructivism*, learning is defined as an individual knowledge construction process being caused by the experience of a specific situation [18, 28]. Learning from a constructivist viewpoint can ideally be achieved by providing an open-world setting with a plethora of interaction possibilities. The mere exploration of the virtual world can initiate the learning process by creating specific situations. The provision of an agent interacting with the player and initiating a reflective learning can be a substitute for the social aspect [8].

3 HORST – THE TEACHING FROG

Horst – The Teaching Frog is a gamified tangible AR learning environment targeting the learning of a frog's anatomy. Learners can virtually dissect a frog, closely inspect each organ, learn about their functions, and test their content knowledge in a quiz. We designed our learning application as a supplementary material for sixth grade biology lessons taught at secondary schools that deal with the amphibian anatomy [16]. The encoded learning contents, e.g., the information displayed about the organs and the procedure of a frog dissection, base on a typically used biology schoolbook [15] and an online frog dissection guide [27]. We transformed the knowledge and conceptualized the pedagogical design of the application in collaboration with pre-service teachers.

Based on the theoretical considerations discussed in section 2 and our pedagogical concept, the learning environment has to fulfill the following requirements:

(1) Require an application of the learning contents
(2) Utilize a gamified approach to increase the motivation
(3) Utilize tangible AR to support the learning process
(4) Provide means to assess the learning progress

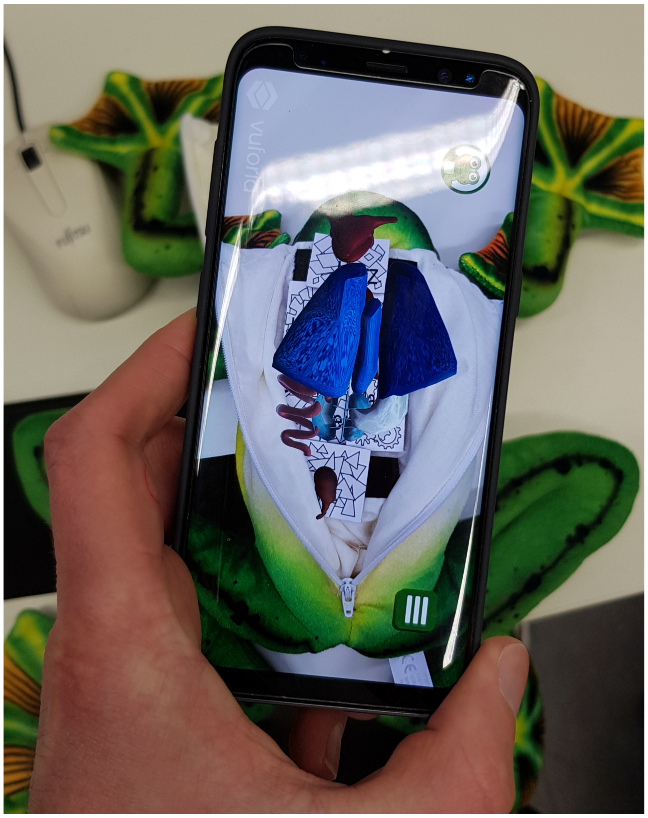

Figure 2: When detecting the markers with a smartphone, the app displays 3D models of the organs.

3.1 Virtual Frog Dissection

Horst – The Teaching Frog is based on a large, but visually realistic soft toy of a frog. For simulating a dissection, we altered the plushfrog by turning its belly into a pouch featuring a zipper. Inside of the pouch, paper-card-based markers are attached to the frog using a small piece of velcro, thus rendering them extractable. By cutting the frog open, i.e., opening the zipper, the markers become visible and can be detected using the camera of a smartphone as Figure 1 displays. Subsequently, our AR application places a 3D model of each organ above the respective target. This visualizes the internal structure of the animal as shown in Figure 2. By extracting a marker, each organ can be closely inspected. When placing an organ next to a magnifying lens marker, further biological details are displayed (see Figure 1).

Learners can choose two dissection modes. The *free mode* allows learners to freely examine the frog and its organs without providing any guidance. The system also gives no feedback about the correctness of the sequence of the dissection. This enables learners to experience learning situations in a self-directed and self-organized way, i.e., following a constructivist approach. Following the theory of cognitivism, the *assisted mode* guides a learner through the procedure of a dissection and provides additional information concerning the position of the organs. After finding and extracting the correct organ, users must place it next to the magnifying lens to learn about its functions and to proceed to the next organ. While progressing through this mode, learners cannot skip steps.

Figure 3: Learners can unlock various achievements. Achievements present well-defined challenges requiring a repetitive interaction with the learning contents.

3.2 Scaffolding the Learning Process

The AR learning environment further includes a quiz to enable learners to assess their learning progress. In its current form, the quiz includes 16 questions testing a user's content knowledge about a frog's anatomy. At the start of a quiz, the sequence of the questions and the possible answer options is randomized. When answering a question correctly, it is removed from the question pool. On a false answer, the application returns the question to the pool at a random position. The quiz further provides a direct feedback system. Answering a question correctly is rewarded with a quack sound and the selected answer is marked with a green color. Selecting a wrong answer results in the sound of a buzzer and the selection being colored in red. Once a learner has answered all questions correctly, the application displays a debriefing screen giving an overview of the selected answers and the correctness of the choices. From there, learners can either restart the quiz or return to the main menu.

For increasing the learners' motivation to repetitively use our application, we implemented a gamification system. In particular, we added highscores and an achievement system. Learners earn points that contribute to their highscore by either finishing an assisted dissection or by performing well in the quiz. Since the learning environment provides multi-user support on the same device, we included a leaderboard allowing learners to compare themselves to their classmates. While the highscores create an incentive for a repetitive use, the achievement system presents well-defined challenges to the users as depicted in Figure 3. For instance, learners receive achievements for inspecting an organ up close or for answering ten questions in a row correctly. Finally, the debriefing screen at the end of a quiz displays a medal featuring up to four stars to reflect a learner's performance.

The implementation of the quiz and the gamification system follows the theory of behavioristic learning. The gamification system provides positive feedback to learners according to their performance in the dissection and the quiz. The quiz itself is a sequence of short and quickly repeatable challenges that immediately provide users with a positive or negative reinforcement.

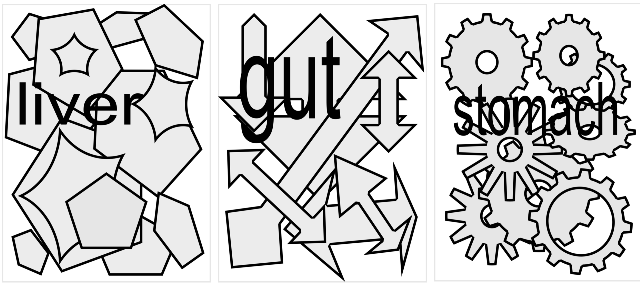

Figure 4: Since the markers overlapped to replicate the internal anatomy of a frog, we composed them from geometrical shapes to achieve a high detectability.

3.3 Technology

The application was developed with *Unity* in the version 2019.2.6f1 [29] and targets smartphones with *Android* from version 4.4 and higher. We implemented the AR functions using the *Vuforia Engine* in the version 8.5.9 [25]. A particular challenge resulted from the overlapping markers inside of the frog's belly. This decision was made to replicate the anatomical structure of the frog. To achieve a good detection of the partly covered markers, we composed them from overlapping geometrical shapes. For instance, the marker of the liver is based on a pentagon shape while marker of the gut is based on the shape of a two-sided arrow as Figure 4 displays. This results in many sharp edges and line-crossings at various angles. These features highly improve the detectability of a marker. Finally, we use strong contrasts, e.g., black and white, to further enhance the quality of the markers.

4 DISCUSSION

Horst – The Teaching Frog is based on a pedagogical design, encodes the learning content of a frog's anatomy in its core interaction possibilities, and provides a quiz to assess the own learning progress. By detecting the markers inside the frog's belly, the application informs learners about the anatomy of a frog. Extracting a marker, i.e., using the advantages of tangible AR, provides further information by either inspecting the organs up close or using the additional magnifying lens marker. As discussed in subsection 2.1, this approach connects the digitally presented information with real world information. In this way, the use of the application as well as the learning process should be very intuitive, elicit a low cognitive load, and lead to an intensified work on the learning materials. A gamification system provides rewards for a repetitive use, hence potentially increasing a learner's motivation to engage in the learning process. Thus, our AR learning environment fulfills the identified core requirements.

With respect to learning, the free mode of the dissection can be helpful to use the application in constructivist teaching and learning environments in the classroom. As being a self-directed process, a learner's active participation is an integral component for constructivist learning [18]. The free mode supports such a self-directed approach by enabling learners to experience specific situations through a free exploration of the learning contents. When using the assisted dissection, the application elicits aspects of cognitivism. Here, our application controls the learning process by guiding the learners through a dissection step-by-step. During such a guided dissection, the application explicitly presents the learning content in an audiovisual way to support the learning process. The quiz, the gamification system, and the individual analysis of the organs reflects aspects of the learning theory of behaviorism. The learning content is segmented into short and quickly repeatable challenges that provide either positive or negative reinforcement,

5 CONCLUSION

Basing on a plushfrog containing extractable markers, *Horst – The Teaching Frog* builds on the advantages of tangible user interfaces for learning. Learners can dissect the frog by opening a zipper at the frog's belly to reveal markers representing the organs. When detected, our AR application displays 3D models of the organs above the respective markers. Removing an organ from the frog allows for a detailed inspection being enhanced by the provision of further information. A quiz allows for a self-assessment of the learning progress. Following a gamified approach, unlocking achievements rewards learners for repetitively using the application.

Future work needs to analyze the system's intuitive use, cognitive load, learning motivation, and learning effectiveness. We intend to compare *Horst – The Teaching Frog* to a traditional schoolbook-based approach and a non-AR as well as paper-based, i.e., the plushfrog is replaced with a 2D image, version of our app. In this study, we expect *Horst – The Teaching Frog* to perform best with respect to the measured qualities. Also, since we target an integration in classroom teaching, it is important to design teaching concepts that use the AR system. Implementing and evaluating these concepts at local schools should result in a higher learning motivation and better learning outcome in comparison to traditional teaching concepts.

Aside from evaluating the learning environment, we further intend to improve the system itself. To enhance the tangible AR aspect, it could be highly beneficial to design physical markers in the form of organ replicates to improve the intuitive use. In addition, parts of the pushfrog itself, e.g., its eyes, could become a marker and provide relevant information about the respective organ. This would simultaneously enhance the tangible aspects of our application.

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