Fly My Little Dragon: Using AR to Learn Geometry

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***Abstract*—We present the gamified AR learning environment *ARES*. During the gameplay, learners guide the little dragon called "Ares" through dungeons. Using AR, *ARES* three-dimensionally integrates the dungeons in the real-world. Each dungeon represents a coordinate system with obstacles that ultimately create mathematical exercises, e.g. rotating a door to let the dragon fly through it. Overcoming such a challenge requires a learner to spatially analyze the exercise and apply the fundamental mathematical principles. *ARES* displays a debriefing screen at the end of a dungeon to further support the learning process. In a preliminary qualitative user study, pre-service and in-service teachers saw great potential in *ARES* for providing further practical and motivating exercises to deepen the knowledge in the classroom and at home.**

***Index Terms*—AR, learning, geometry, gamification**

I. Introduction

The acquisition of new knowledge is a challenging task that requires a high degree of motivation, discipline, and high amount of work [1]. The challenge of learning becomes even more difficult when the learning content is complex and can neither be demonstrated nor comprehended easily [2]. Such a difficult learning content can be the use of coordinate systems for 2D and 3D geometry. Learners must understand how the underlying math describes objects and the spatial relationships between them.

Using a gamified approach can improve the learning motivation in the case of complex learning contents [2]. The widespread availability of mobile devices, especially smartphones [3], among students allows for those technology-based teaching concepts [4]. Smartphones further provide an easy access to Augmented Reality (AR) in classrooms leading to an increased motivation and higher task performance [5].

Besides the motivational aspects, AR learning environments provide a spatial and direct visualization of the encoded learning contents in the real-world [6]. This especially can be beneficial for the learning of complex concepts like geometry. Therefore, the development of a gamified AR learning environment for coordinate systems could improve the acquisition of this knowledge and increase the overall learning motivation.

II. Theoretical Background

AR augments the real-world by three-dimensionally integrating in real time interactive virtual elements into it [7]. Users can experience these augmentations using headworn, handheld, and projected displays [8]. Due to the widespread availability of smartphones among young students, handheld AR currently seems to be beneficial for a classroom integration of AR learning environments.

A. AR in an Educational Context

Despite targeting target almost any kind of scientific area, AR learning environments mostly focus on STEM related topics [5]. For instance, *Mathland* demonstrates the mathematics behind the Newtonian physics and allows users to modify and thus explore the physical laws [9]. *Geo+* supports primary school students in learning about solid geometry [10]. The learning environment visualizes three-dimensional geometrical objects, thus facilitating the development of a spatial understanding. This suggests that AR could also be beneficial for the learning of spatial geometry and coordinate systems.

B. Pedagogical Design of Learning Environments

Three main theories attempt to approach a definition of the underlying processes of learning, i.e., the theories of *behaviorism*, *cognitivism*, and *constructivism* [11]. These theories can provide guidelines for the pedagogical design of AR learning environments.

The theory of *behaviorism* describes an individual learning process as a black box and focuses on feedback. Behavioristic learning occurs through a repetition of the learning contents combined with a positive or negative reinforcement by the environment [11]. In the context of serious games design, behavioristic learning can be achieved by implementing rewards, punishments, and an episodic gameplay like short and quickly repeatable levels.

According to the theory of *cognitivism*, a learning process leads to the development of internal cognitive structures [11]. A learning environment following a cognitivist design motivates the learning process and the application of the learning content with a specific problem. It further introduces learners to new knowledge using a tutorial. Subsequent challenges follow the tutorial, thus leading to further applications of the learning content. To support the learning process, learning environments should explicitly present a learner's actions and their results in an audiovisual way. Finally, the difficulty of the objectives should be adjusted to the current knowledge level and experience of the learners.

Finally, the theory of *constructivism* defines learning as an individual knowledge construction process evoked by the experience of a specific situation [11]. In this way, constructivist learning should ideally be achieved by providing an open-world setting with a plethora of interaction possibilities. The mere exploration and interaction with the virtual world creates specific situations and hence can initiate a learning

Fig. 1. ARES challenges learners to guide a little dragon through dungeons. Each dungeon represents a coordinate system and provides a sequence of challenges, i.e., learning exercises (left). Completing challenges rewards learners with points they can invest in new skins for their little dragon (right).

process. The learning environment can further provide an agent interacting with the player to initiate a reflective learning and to substitute for the social aspect [12].

III. System Description

ARES is an AR learning environment for 2D and 3D geometry with a focus on coordinate systems. We designed ARES to teach encoded learning contents and to foster already learned concepts. It provides gamification elements throughout the gameplay to motivate intended learning processes. ARES targets seventh and higher grade math lessons.

ARES follows a cognitivist design. The goal of the game is to guide a small dragon through coordinate system dungeons. Each dungeon provides a different sequence of learning exercises posed as gamified challenges. These challenges include the determination of points in 2D and 3D coordinate systems as well as the scaling and the rotation of objects. Solving these math exercises requires the knowledge and application of underlying geometrical concepts. ARES explicitly demonstrates the application of the knowledge in an audiovisual and spatial way, thus leading to the development of internal cognitive structures. To allow for such a spatial analysis, ARES visualizes each dungeon and hence the gameplay using AR. This is done by scanning individual markers for each of the dungeons. Pre-service teachers collaborated with us on the design of the learning exercises and pedagogical concepts.

A. Gameplay

A learning process starts by scanning one of the markers to display a dungeon at the marker's position. Each dungeon features a starting point, an end point, and one or more learning challenges. The dragon spawns at the starting point. By solving the sequence of challenges, the dragon moves on from one challenge to the next. The learning environment indicates the current challenge with a white highlight which turns yellow upon selection. Currently, ARES supports three types of challenges and represents them by specific objects:

(1) **Coordinates in Space:** Candelabra are direct waypoints through a given dungeon of the little dragon. Learners need to use their coordinates in space (x,y,z) as inputs to guide the little dragon from one candle holder to the next one as displayed in Figure 1.

Fig. 2. Besides earning points for the shop, learners can unlock various achievements. These two gamification elements are intended to increase a learner's motivation.

(2) **Scaling:** Scalable objects in each room like spiked traps appear together with a translucent green box indicating the target dimensions. A learner scales such an object by entering a scale factor.

(3) **Rotation:** Turnable objects appear as doors in conjunction with a green box indicating their target rotation. Learners give free passage to the little dragon by using the desired rotation angle in degrees.

A learner can select a challenge by touching the relevant object on the display of the smartphone. This opens an input menu allowing learners to enter the self-obtained results. The learning environment assists a learner by displaying the currently required action at the bottom of the screen. A help button in the upper right corner provides a short explanation and graphical help for each task. Our interface and the gameplay is illustrated in Figure 1 left. Completing a challenge requires learners to understand the fundamental principles of the respective mathematical operation and visualizes the learning content in the virtual environment.

After solving the last challenge of a given dungeon, the little dragon flies to the end point, thus successfully completing the dungeon. Subsequently, a debriefing screen summarizes the inputs and solutions for the dungeon. This provides feedback about the correctness of a learner's approach and hence allows them to analyze their learning progress [13]. Finally, ARES rewards the learner with achievements and experience points depending on the difficulty of the challenges of a given dungeon as displayed in Figure 2. This feature allows for behavioristic teaching concepts by providing positive reinforcements. In addition, these gamification elements can increase a learner's motivation to continue using the learning environment over a longer period of time. The experience points can be exchanged for different skins for the little dragon in a shop as shown in Figure 1 right. Unlocking certain achievements also rewards these skins.

The learning environment assists teachers in explaining the underlying gameplay by providing a short interactive tutorial. Using text boxes and highlighting of objects, it explains how a learner can determine a specific coordinate and scale an object. The tutorial works without scanning a marker. We made this decision to allow learners to complete the tutorial at home in preparation for the next lesson.

Finally, we added a little easter egg to the learning environment. The app displays the little dragon in the main menu. Upon touch, it performs a pirouette and emits a shriek.

B. Technology

The learning environment was developed with *Unity* version 2020.1.10f1. We used *Vuforia 9.7.4* to implement AR and marker recognition in our application and used assets by *Quaternius*. The application runs on *Android* devices only and is intended to be used with *ARcore* devices. We designed our image targets to be easily distinguishable by both users and our application. A future version of ARES shall include a graphical novel introducing the individual dungeons. This would allow for every page of the novel to act as a marker, thus improving the overall presentation of the learning environment.

IV. Evaluation

We conducted a preliminary user study with pre-service and in-service teachers to validate the overall design as well as to test the feasibility of integrating ARES in classroom teaching concepts. We also gathered suggestions for improvement.

A. Methods

We asked our participants the following questions:

1) How would you integrate this app in a classroom teaching context?
2) What aspects of this app did you like?
3) What aspects did you dislike?
4) Why would you use this app for teaching?
5) Where does this app have problems concerning practical use?
6) How could we improve this app?

B. Participants

We recruited five participants for our user study (three men aged 29, 31 and 32 years old; two women aged 22 and 29). The participants took part in the study on a voluntarily basis. Three of them were in-service teachers, two were pre-service teachers. All participants combined had a teaching experience of 4.33 years on average. All participants were fluent in the German language and were right-handed. None of the participants had visual or auditory impairments. Previous experience with AR was low for all participants: one had never used it before, two had only used it for scientific studies, and the other two use it around once a year. Since the study took place during the COVID-19 pandemic, we remotely conducted each test by video call. The participants installed the application on their own devices prior to the experiment.

C. Procedure

After welcoming the participants, we gave them a short explanation about the purpose of the user study. The participants signed an informed consent form and completed a demographics questionnaire. Subsequently, we asked the participants to complete the tutorial to get an overview of the basic controls and functionality. After having familiarized themselves with the app, the participants completed three dungeons, each containing multiple exercises of a single challenge type. Afterwards, the participants were free to explore the remaining features of the app, such as the achievements and the shop. Finally, the participants answered the qualitative questions in an online questionnaire.

V. Results

All participants reported that they would generally use the application as supplementary material for their classroom teaching. However, one participant works in the area of special needs education and hence cannot personally use the application as spatial geometry is too complex for the pupils. The participants listed (1) deepening the learning content, (2) practicing the just learned knowledge at the end of a lesson, (3) individual practice, and (4) fostering the determination of points in a coordinate system as ideal use cases for ARES. According to them, these aspects would make the subject of spatial geometry more accessible, descriptive, and intuitive as well as also increase the pupils' motivation. Depending on the general behavior of the class, one of the participants also considered to only use the learning environment for further practice at home to avoid too much distraction.

The participants found ARES intuitive, fast, and easy to use. In addition, they enjoyed analyzing the coordinate system dungeons from different angles. One participant especially pointed out that the direct and spatial presentation of the gameplay using AR is impressive. They further enjoyed the aspect of guiding and even directly interacting with the little dragon. Overall, they expected a higher learning motivation when using the AR learning environment for teaching and learning. However, the participants criticized the tutorial as it was not detailed enough with regards to the explanation of the underlying mathematics.

Two participants, however, missed a version that works without AR markers. This would provide the pupils with greater freedom as they could use the app anywhere like while sitting on the couch or lying in bed. One participant also was concerned that pupils could use the smartphone for other purposes than learning in a classroom.

To improve the app, the participants proposed more detailed descriptions and step-by-step demonstrations of solving the challenges. Additionally, more examples in the help and tutorial section would make it easier for students to use the learning environment. One participant desired even harder challenges with more steps that have to be solved in sequence.

VI. Discussion

All in all, our preliminary results indicate that the application is suitable for teaching. It makes spatial geometry accessible to students, is intuitive, and easy to use. The benefits of AR, like being able to view learning exercises from different angles, were well received. Our application shows great potential, especially when used for additional practice at home, where it might increase student motivation. This outcome validates the design of ARES and its underlying pedagogical concept.

However, there are some improvements to be made. The help section is not detailed and accessible enough. It needs to be more prominent and explain each learning exercise in easy to understand steps and images. The tutorial lacks depth, as it only showcases two of the three challenges, and explains them in one sentence each. These problems could be improved upon by (1) including every challenge type in the tutorial, (2) provide a detailed description of the underlying mathematical principles, and (3) making this information available everywhere in the application. Overall, we recommend that *learning environments should provide a detailed explanation of the learning contents*.

Finally, the participants raised concerns about the general classroom implementation of smartphone-based learning environments. Using AR in an educational context can evoke certain challenges for the teacher. For instance, attention tunneling results in a pupil's strong focus on the app only [5], [14]. This, however, is not an effect caused by ARES, but an aspect that requires specific competencies and planning with regards to technology-based teaching [15].

VII. Conclusion

In this paper, we presented the gamified AR learning environment ARES. By utilizing the potential of AR to directly and spatially visualize complex concepts, ARES assists the learning of using coordinate systems for 2D and 3D geometry. During the gameplay, learners must solve mathematical exercises to guide a little dragon through a dungeon. The learning environment displays the dungeons three-dimensionally on a learner's desk. This allows for a spatial analysis of the coordinate system and existing objects, thus potentially improving the learning of this knowledge. The gamified approach and the quest of helping the little dragon should result in a higher learning motivation. At the end of each dungeon, ARES displays a debriefing screen to scaffold the learning process. In a user study, pre-service and in-service teachers enjoyed the spatial and motivating presentation of the learning content. They further saw great benefits in using ARES for fostering the knowledge at home.

Future work shall aim at an evaluation of the learning effectiveness. After implementing the suggested improvements, we intend to test ARES at local schools and to compare it to a traditional textbook approach. Also, future work shall create a visual novel extended by AR to embed in learning process in a narrative.

References

[1] P. Ur, *A Course in Language Teaching*. Cambridge University Press, 1996.

[2] S. Oberdörfer, "Better learning with gaming: Knowledge encoding and knowledge learning using gamification," Ph.D. dissertation, University of Würzburg, 2021.

[3] bitkom, "Mit 10 jahren haben die meisten kinder ein eigenes smartphone," https://www.bitkom.org/Presse/Presseinformation/Mit-10-Jahren-haben-die-meisten-Kinder-ein-eigenes-Smartphone, 2020.

[4] J. Gikas and M. M. Grant, "Mobile computing devices in higher education: Student perspectives on learning with cellphones, smartphones & social media," *The Internet and Higher Education*, vol. 19, pp. 18–26, 2013.

[5] J. Bacca, S. Baldiris, S. Fabregat, S. Graf, and Kinishuk, "Augmented reality trends in education: A systematic review of research and applications," *Educational Technology & Society*, vol. 17, no. 4, pp. 133–149, 2014.

[6] P. Diegmann, M. Schmidt-Kraepelin, S. Van den Eynden, and D. Basten, "Benefits of augmented reality in educational environments - a systematic literature review," in *Proceedings of the 12th International Conference on Wirtschaftsinformatik*, Osnabrück, Germany, March 2015, pp. 1542–1556.

[7] R. T. Azuma, "A survey of augmented reality," *Presence: Teleoperators and Virtual Environments*, vol. 6, no. 4, pp. 355–385, 1997.

[8] K. Kim, M. Billinghurst, G. Bruder, H. B. Duh, and G. F. Welch, "Revisiting trends in augmented reality research: A review of the 2nd decade of ismar (2008–2017)," *IEEE Transactions on Visualization and Computer Graphics*, vol. 24, no. 11, pp. 2947–2962, 2018.

[9] M. Khan, F. Trujano, A. Choudhury, and P. Maes, "Mathland: Playful mathematical learning in mixed reality," in *CHI'18 Extended Abstracts*, Montréal, Canada, April 2018.

[10] V. Rossano, R. Lanzilotti, A. Cazzolla, and T. Roselli, "Augmented reality to support geometry learning," *IEEE Access*, vol. 8, pp. 107 772–107 780, 2020.

[11] M. Kerres, *Mediendidaktik: Konzeption und Entwicklung digitaler Lernangebote*, 5th ed. Berlin/Boston: De Gruyter, 2018.

[12] K. Bucher, T. Blome, S. Rudolph, and S. von Mammen, "Vreanimate ii: training first aid and reanimation in virtual reality," *Journal of Computers in Education*, vol. 6, no. 1, pp. 53–78, 2018.

[13] D. Crookall, "Serious games, debriefing, and simulation/gaming as a discipline," *Simulation & Gaming*, vol. 41, no. 6, pp. 898–920, Jan. 2011.

[14] I. Radu, "Augmented reality in education: A meta-review and cross-media analysis," *Personal Ubiquitous Computing*, vol. 18, no. 6, pp. 1533–1543, 2014.

[15] S. Oberdörfer, S. Birnstiel, M. E. Latoschik, and S. Grafe, "Mutual benefits: Interdisciplinary education of pre-service teachers and hci students in vr/ar learning environment design," *Frontiers in Education, Section Teacher Education*, 2021.