IMPLEMENTING AUGMENTED REALITY IN FLIPPED MATHEMATIC CLASSROOMS TO ENABLE INQUIRY-BASED LEARNING

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When learning mathematics following flipped classroom approaches, students most often have to watch videos as homework before class. Teachers should consider not consistently using a video where a new concept is introduced at the beginning of the learning process. If it suits the learning material, learners could first explore the problem independently and afterwards they could watch a video to consolidate their findings. By implementing augmented reality (AR) activities in flipped classroom scenarios, inquiry-based learning can be fostered. But, designing such sequences can be challenging for educators. Thus, this paper describes the development of teaching model templates for AR-based flipped classroom scenarios. Using a design-based research approach, further research activity will focus on the evaluation of the proposed teaching model templates to investigate how mathematics teachers adapt the templates to their teaching needs.

Keywords: augmented reality, flipped classroom, inquiry-based learning, student-centred learning

INTRODUCTION AND THEORETICAL BACKGROUND

The development of AR applications (for instance GeoGebra AR) provides new possibilities to support learning processes in mathematics education. Though Samuelsson (2006) accentuates that it is not only using technologies that should be central but above all the way how new technologies are used in mathematics education that determines the orientation and thus the success of mathematics lessons - namely utilising technologies for discovering and exploring mathematics. Johnson et al. (2011) point out that AR can be used especially to support inquiry-based learning through exploration. Learners need enough time to explore new phenomena at their own pace. The implementation of AR activities in flipped classroom environments can lead to more in-class time, which can then be used for exploration.

Azuma (1997) defines AR as an interactive real-time technology, which combines and registers real and virtual objects in real 3D space. Spatial problems, which are difficult to grasp in 2D, can be presented and explored in 3D using AR (Woods et al., 2004). Furthermore, Seichter (2007) found out that AR supports the development of spatial abilities, and according to Pemberton and Winter (2009) the use of a collaborative AR environment can support students in acquiring a deeper understanding of concepts by generating knowledge in groups and reflecting on their experiences. Moreover, several studies (Dünser & Hornecker, 2007; Lamanauskas et al., 2008) indicate that AR activities can increase students' motivation.

Lage, Platt and Treglia (2000) define the key-term "inverting" of flipped classroom as follows: "Inverting the classroom means that events that have traditionally taken place inside the classroom now take place outside the classroom and vice versa" (p. 32). Therefore, in traditional flipped classroom environments, students usually have to watch videos before class, and the in-class phase is used for different student-centred, group-based or problem-solving activities. More and more research projects (e.g., Esperanza, Fabian & Toto, 2016) demonstrate that flipped classroom approaches can improve students' achievement in learning mathematics. But rather than merely presenting facts or worked-out examples, the learning process in a flipped mathematics classroom can also be initiated by posing questions or problems, thus fostering inquiry-based learning. According to Bloom's taxonomy (1956), inquiry-based learning is fundamental for the development of higher-order thinking. However, only a few studies (e.g. Raouna & Lee, 2018) are available on how to design learning activities in a flipped classroom that encourage higher-order conceptual thinking. Moreover, few attempts (e.g., Bujak et al., 2013) have been made to investigate the role of AR in mathematics teaching, and many unanswered questions remain about the integration of AR activities/environments in mathematics education. For instance, how to integrate AR learning activities effectively in blended learning scenarios such as flipped classroom environments is still unknown (Ibáñez & Delgado-Kloos, 2018). So, it is important to investigate how AR-based flipped classroom sequences should be designed to enable inquiry-based learning in mathematics education.

In order to achieve the research aim, teaching model templates are developed with regard to existing literature. The proposed teaching model templates should act as a guide to assist secondary mathematics teachers designing AR-based flipped classroom scenarios focusing on inquiry-based learning.

From the design perspective, the development of the templates adopts design-based research (Reimann, 2011) as a study method to improve practice and advance the theory of learning. According to Bakker (2018), research and development in this research methodology are closely linked. Through various iterative design-cycles, the teaching model templates will be applied in practice, and then refined. However, the goal is not to validate and compare the two templates during a field trial.

DESIGN OF THE TEACHING MODEL TEMPLATES

In the following section, two recently developed teaching model templates for AR-based flipped classroom scenarios are presented. These templates are built on inquiry-based pedagogies. We use inquiry-based learning as an umbrella term and regard problem-based learning as a specific way of learning through inquiry.

Inquiry-based teaching model template

The development of inquiry goes back to John Dewey, who developed it in the twentieth century (Dewey, 1938). His model is based on five cyclical phases: "asking questions, investigating solutions, creating new knowledge as information is gathered, discussing discoveries and experiences, and reflecting on new found knowledge" (Crippen & Archambault, 2012).

According to Albion (2015), the lowest common denominator of all inquiry-based pedagogies is a "big question" that serves as a starting point. This question is sometimes also described in a broader sense as a problem or project. In inquiry-based learning environments, teachers support the learning process and provide knowledge. However, the teachers' role as a knowledge provider should not be the most crucial aspect in such learning scenarios.

In science education, the 5-E instructional model is a widely used inquiry-based learning pedagogy; it employs five phases: Engage, Explore, Explain, Elaborate and Evaluate (Bybee, 2009). The five stages are described as follows:

Phase 1 (Engagement): includes the activation of prior knowledge and should help students to become engaged in new concepts through promoting curiosity.

Phase 2 (Exploration): provides learners with hands-on exploration activities upon which they formulate concepts, processes and skills.

Phase 3 (Explanation): involves student’s explanations of an aspect of their exploration experiences, and also provides opportunities for teachers to introduce a concept, theory or principle that may guide learners toward a more in-depth understanding.

Phase 4 (Elaboration): facilitates the transfer of concepts to new closely related situations to help students develop deeper understanding.

Phase 5 (Evaluation): engages students to self-assess their understanding and offers opportunities for educators to evaluate students' progress toward achieving educational goals.

For developing the inquiry-based teaching model template for AR-based flipped classrooms, the 5-E instructional model was used. Table 1 presents the designed teaching model template, which includes a description of different activities in the classroom (“in-class”) and outside the physical learning space of the classroom (“out-of-class”).

5-E model phase	“Out-of-class” activities	“In-class” activities
1. Engagement	Teacher introduces the educational scenario to provoke curiosity and tries to activate prior knowledge using digital material (e.g. interactive video with integrated questions). Students go through the provided material at their own pace and note any questions that arise.	Teacher leads classroom discussion, and the question for investigation is developed. Students engage in the classroom discussion.
2. Exploration	Teacher presents the AR environment to be explored. Students prepare for class by inspecting the environment presented.	Teacher supports the exploration process and encourages learners to formulate concepts, processes and skills based on their experiences. Students explore the AR environment and share their findings with the class.
3. Explanation	Teacher introduces relevant concepts or theories that might have escaped students’ notice to foster deeper understanding. Students study the provided material.	Teacher and students utilise the concept and the experiences to describe and explain the phenomenon and answer the initial question.
4. Elaboration	Teacher describes new situations when appropriate using digital media (e.g. video). Students try to identify new situations.	Teacher promotes elaboration. Students apply the knowledge gained to new situations (when appropriate in an AR environment).
5. Evaluation	Teacher provides self-assessment for learners.	Teacher uses formal assessment to evaluate students' progress towards

	Students engage in the self-assessment task to reflect on their learning process.	achieving educational goals.

Table 1. 5-E instructional model template

Table 1 shows the inquiry-based teaching model template suggests teaching/learning activities for each 5-E phase. This template can act as a blueprint for teachers, which can be further adapted to their own teaching needs and preferences. As flipped classroom approaches propose, learner-centred activities have been included in the teacher-supported face-to-face sessions to encourage higher-order thinking, whereas the "out-of-class" phases are aimed at students' engagement with the resources provided.

The AR environment implemented in the exploratory phase is intended to enable inquiry-based learning and should be only used if it is beneficial for the learning process. Moreover, in the stage of elaboration, students should have the opportunity to exchange their thoughts in a collaborative AR scenario. The use of such an environment should help learners to develop a deeper understanding of concepts, as Pemberton and Winter (2009) suggest.

Problem-based teaching model template

In the 1960s, problem-based learning evolved from innovative medical education in North America (Boud & Feletti, 1997). As in the case of inquiry-based learning, the roots of problem-based learning can be found in Dewey's philosophy, whereby inquiry-based learning can be considered as a parent (Albion, 2015). Hmelo-Silver et al. (2007) describe problem-based learning as opportunities for learners to work collaboratively in groups on problem solutions, learn in a self-directed manner, apply the knowledge gained to new situations, and reflect about what they have learned and the effectiveness of the strategies used.

The selection of an interdisciplinary problem is crucial for the success of problem-based learning. Equally crucial for success is a teacher who accompanies the learning process. Problem-based teaching approaches have much in common with the above-mentioned inquiry-based pedagogies. In both learning environments, students construct their understanding through experiencing and reflecting. Therefore, both approaches can be seen as constructivist ways of learning; however, what characterises problem-based learning is the role that teachers play. In inquiry-based learning scenarios, teachers are facilitators of learning and knowledge providers, whereas in problem-based learning environments teachers do not offer information regarding the problem (Savery, 2006).

In the context of mathematics education, different studies (e.g., Padmavathy & Mareesh, 2013) showed that problem-based learning is effective in improving students' understanding and the ability to apply newly learnt concepts in real life. Thus, the described teaching model template described below is based on the problem-based learning framework presented by Eggen and Kauchak (2012). Implementing problem-based learning is conducted in four phases that are outlined here:

Phase 1 (Problem Presentation): includes the representation and modelling of the interdisciplinary problem to be investigated. It is essential to activate prior knowledge in this phase.

Phase 2 (Problem Solving Strategy Development): engages learners to formulate and select the strategy for solving the interdisciplinary problem.

Phase 3 (Problem Solving Strategy Implementation): involves the implementation of the selected strategy for solving the interdisciplinary problem.

Phase 4 (Discussion & Evaluation): embraces reflections on students' solutions based on the teacher's and peers' feedback.

Table 2 presents the problem-based teaching model template that has been developed; it includes a description of activities in the classroom ("in-class") and beyond the physical learning space of the classroom ("out-of-class").

Problem-based learning phase	"Out-of-class" activities	"In-class" activities
1. Problem Presentation	Teacher presents the interdisciplinary problem to provoke curiosity and shares digital support material for modelling the problem. Students try to identify the problem to be solved and study the material offered.	Teacher leads classroom discussion to eliminate ambiguities and supports learners in modelling the problem. Students model the interdisciplinary problem with AR technology if it facilitates the problem-solving process.
2. Problem Solving Strategy Development	Teacher provides collaborative AR environment (when appropriate) for learners. Students think about suitable problem-solving strategies and share their first thoughts in the environment provided.	Teacher supports learners during the development of the problem-solving strategies but should not offer additional information regarding the problem. Students discuss and select the optimal strategy for solving the problem in groups.
3. Problem Solving Strategy Implementation	Teacher provides feedback on the selected optimal strategy. Students exchange their selected strategy for solving the problem with other groups and give feedback.	Teacher facilitates the implementation of the selected strategy. Students implement the selected problem-solving strategy based on the teachers' and peers' feedback and record their findings.
4. Discussion & Evaluation	Teacher presents possible solutions or an optimal strategy using digital media (e.g. interactive video with integrated questions). Students study resources provided and note any questions or remarks that arise.	Teacher leads classroom discussion based on learners' questions and remarks and gives feedback. Students engage in the classroom discussion and reflect on their learning process.

Table 2. Problem-based learning template

Similar to the previously presented inquiry-based teaching model template, the template described in Table 2 can be seen as a design guide for educators describing activities linked to each phase of the problem-solving cycle. To help teachers orchestrate the learning scenario, the template also suggests a distribution of the aforementioned activities inside and outside the classroom according to flipped classroom approaches.

Modelling the problem in an AR environment can be helpful. AR allows spatial problems that are difficult to detect in 2D to be displayed and investigated in 3D (Woods et al., 2004). The representation of the problem with AR technology has been integrated in the teaching model template in the phase of the problem presentation; however, AR should only be used if it adds value to the problem-solving process. Furthermore, learners can apply the knowledge acquired in new situations in an AR environment if the use of AR is appropriate and beneficial.

CONCLUSION AND FUTURE RESEARCH ACTIVITIES

Inquiry-based and problem-based learning are considered as student-centred approaches where learners actively ask questions, collaboratively solve problems, and reflect on their own experiences. In AR environments, learners can learn by inquiring. Combining AR with flipped classroom scenarios, teachers can offer enough in-class time for exploration. But, designing such scenarios can be challenging for educators.

The teaching model templates presented aim to provide a design guide for teachers when implementing AR activities in flipped mathematic classrooms and can foster inquiry-based and problem-based learning. Furthermore, the developed templates can act as guidelines for the flexible implementation of flipped classroom approaches. More specifically, for the construction of different mathematical meanings, students should first be allowed to explore the problem independently instead of watching a concept being explained in a video. Afterwards, a video can be provided as homework to consolidate the findings. Therefore, depending on the learning content, flipped classroom approaches should not be continuously used as a form of direct instruction in mathematics teaching.

The teaching model templates are considered a priori in an on-going project. Therefore, future research will have to determine whether the teaching model templates provided facilitate mathematics teachers to design AR-based flipped classroom scenarios. According to a design-based research approach, the next step is to implement them in practice and refine them. Moreover, it would be interesting to investigate how teachers adjust and further adapt the developed templates towards meeting their own teaching needs.

REFERENCES

Albion, Peter (2015). Project-, problem-, and inquiry-based learning. In *Teaching and digital technologies: big issues and critical questions.* Cambridge University Press, Port Melbourne, Australia, 240-252.

Azuma, R.T. (1997). A Survey of Augmented Reality. In Presence: *Teleoperators and Virtual Environments*, 6(4), 355-385.

Bakker, A. (2018). *Design Research in Education, A Practical Guide for Early Career Researchers.* London, UK: Routledge.

Bloom, B.S. (Ed.), Engelhart, M.D., Furst, E.J., Hill, W.H., & Krathwohl, D.R. (1956). *Taxonomy of educational objectives: The classification of educational goals*. Handbook 1: Cognitive domain. New York: David McKay.

Boud, D., & Feletti, G. (1997). *The challenge of problem-based learning* (2nd ed.). London: Kogan Page.

Bujak, K. R., Radu, I., Catrambone, R., MacIntyre, B., Zheng, R., & Golubski, G. (2013). A psychological perspective on augmented reality in the mathematics classroom. *Computers & Education*, 68, 536–544. https://doi.org/10.1016/j.compedu.2013.02.017

Bybee, R. W. (2009). *The BSCS 5E Instructional Model and 21st Century Skills*. Washington, DC: National Academies Board on Science Education.

Crippen, K. J., & Archambault, L. (2012). Scaffolded Inquiry-Based Instruction with Technology: A Signature Pedagogy for STEM Education. *Computers in the Schools*, 29(1–2), 157–173. https://doi.org/10.1080/07380569.2012.658733

Dewey, J. (1938). *Experience and education*. New York, NY: Touchstone Books.

Dünser, A., & Hornecker, E. (2007). An Observational Study of Children Interacting with an Augmented Story Book. In K. Hui, Z. Pan, R. C. Chung, C. C. L. Wang, X. Jin, S. Göbel, & E. C.-L. Li (Eds.), *Technologies for E-Learning and Digital Entertainment* (Vol. 4469, pp. 305–315). Berlin, Heidelberg: Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-540-73011-8_31

Eggen, P., & Kauchak, D. (2012). *Strategies and Models for Teachers: Teaching Content and Thinking Skills* (6th ed.). Boston: Pearson.

Esperanza, P., Fabian K. & Toto C. (2016). Flipped Classroom Model: Effects on Performance, Attitudes and Perceptions in High School Algebra. In K. Verbert (Ed.), *Adaptive and Adaptable Learning* (pp. 85-97). Lyon, France: Springer.

Hmelo-Silver, C. E., Duncan, R. G., & Chinn, C. A. (2007). Scaffolding and Achievement in Problem-Based and Inquiry Learning: A Response to Kirschner, Sweller, and Clark (2006). *Educational Psychologist*, 42(2), 99-107. doi: 10.1080/00461520701263368

Ibáñez, M.-B., & Delgado-Kloos, C. (2018). Augmented reality for STEM learning: A systematic review. *Computers & Education*, 123, 109–123. https://doi.org/10.1016/j.compedu.2018.05.002

Johnson, L., Smith, R., Willis, H., & Levine, A. H. (2011). *The 2011 Horizon Report*. Austin, Texas: The New Media Consortium.

Lage, M., Platt, G. & Treglia, M. (2000). Inverting the classroom: A gateway to creating an inclusive learning environment. *Journal of Economic Education*, 31(1), 30-43.

Lamanauskas, V., Vilkonis, R. & Bilbokaite, R. (2008). Pedagogical Evaluation of the Augmented Reality Platform. *Internal Report on Task 5.3 in the ARISEproject*, Šiauliai University, Lithuania.

Padmavathy RD, dan Mareesh K(2013). Effectiveness of Problem Based Learning In Mathematics. *Int. Multidiscipl.e-J.*, 2(1), 45-51.

Pemberton, L., & Winter, M. (2009). Collaborative augmented reality in schools. *Proceedings of the 9th international conference on Computer supported collaborative learning - CSCL'09* (Vol. 2, pp. 109–111). Rhodes, Greece: Association for Computational Linguistics. https://doi.org/10.3115/1599503.1599540

Raouna, M. L., & Lee, K. (2018). *A Flipped Classroom Model for Inquiry-Based Learning in Cyprus Primary Education Context*.

Reimann, P. (2011). Design-Based Research. In L. Markauskaite, P. Freebody, & J. Irwin (Eds.), *Methodological Choice and Design* (pp. 37–50). Springer Netherlands.

Samuelsson, J. (2006). ICT as a Change Agent of Mathematics Teaching in Swedish Secondary School. *Education and Information Technologies*, 11(1), 71–81. https://doi.org/10.1007/s10639-005-5713-5

Savery, J. R. (2006). Overview of Problem-based Learning: Definitions and Distinctions. *Interdisciplinary Journal of Problem-Based Learning*, 1(1). https://doi.org/10.7771/1541-5015.1002

Seichter, H. (2007). Augmented Reality and Tangible Interfaces in Collaborative Urban Design. In A. Dong, A. V. Moere, & J. S. Gero (Eds.), *Computer-Aided Architectural Design Futures* (CAADFutures) 2007 (pp. 3–16). Dordrecht: Springer Netherlands. https://doi.org/10.1007/978-1-4020-6528-6_1

Woods, E., Billinghurst, M., Looser, J., Aldridge, G., Brown, D., Garrie, B., & Nelles, C. (2004). Augmenting the science centre and museum experience. *Proceedings of the 2nd international conference on Computer graphics and interactive techniques in Austalasia and Southe East Asia - GRAPHITE '04* (p. 230). Singapore: ACM Press. https://doi.org/10.1145/988834.988873

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