Using Activity Led Learning for Teaching Computer Graphics Principles Through Augmented Reality

F. Liarokapis

HCI Laboratory, Masaryk University, Brno, Czech Republic

Abstract

In this paper, an activity-led learning approach is applied to computer graphics students at Masaryk University for the Master's course called "Augmented Reality Interfaces". The scope of this research is to demonstrate the learning effectiveness of augmented reality and project development approaches for higher education teaching. Students were presented with the theoretical background in augmented reality in the classical way (lectures) and were asked to implement the assignment using active learning approaches. The aim of the assignment was to design and implement an augmented reality interface demonstrating various computer graphics aspects which could be used to enhance the teaching process. Their main focus was to concentrate on three aspects: interface design, interaction mediums and collaboration aspects. Data was collected for two consecutive academic years (one semester with 13 weeks per year) and results showed a very high pass-rate as well as increased engagement and student satisfaction. However, students found that this sort of approach is harder than other approaches.

Categories and Subject Descriptors (according to ACM CCS): H.5.1 [Multimedia Information Systems]: Artificial, augmented, and virtual realities—Evaluation/methodology

1. Introduction

Augmented reality (AR) can be considered as a collection of computer graphics, computer vision and multimedia technologies that operate in conjunction, with the aim of enhancing the user's perception of the real world through multimedia information. In recent years, with the rapid advances of visual tracking and user interface design, a number of AR tools have started to evolve into powerful tools. Reports predict that revenues from AR will be close to 100 billion USA dollars by 2020. Moreover, the educational market for virtual and augmented reality is predicted to reach 300 billion USA dollars by 2020 [BCS*16].

The potential benefits of AR applied in higher education were first documented in 2005 [Lia05] and then in 2010 [LA10] and included: (a) *multi-modal visualisation of difficult theoretical concepts*; (b) *practical exploration of the theory through tangible examples*; (c) *natural interaction with multimedia representations of teaching material*; and (d) *effective collaboration and discussion amongst the participants*. In 2011 [YYJ11], a classification of AR applications into five groups was proposed as follows: discovery-based learning, objects modelling, AR books, skills training and AR gaming.

In 2014, factors such as: the uses, advantages, limitations, effectiveness, challenges and features of augmented reality in educational settings were investigated [BBF*14]. More recently, other benefits of AR in educational environments identified 14 different types including [DKEB15]: motivation, attention, concentration, satisfaction, student-centered learning, collaborative learning, details, accessibility information, interactivity, learning curve, creativity, spatial abilities, memory and reduced costs. Student-centered learning is not a new concept and it is focused on providing students with a specific problem, scenario, task or activity in order to motivate, engage and stimulate them for providing effective and efficient solutions.

The aim of this paper is to demonstrate the learning effectiveness of AR and project development approaches for higher education teaching. It is a follow-up of past research [LA10], [Lia12], but goes a step further by combining Activity Led Learning (ALL) techniques (see section 2) [APH*12], with AR. Similar approaches (i.e. discovery-based learning) were also combined in the past such as: in collaborative learning in mathematics and geometry education [KS03], in computer games technology [AP09] engineering graphics education [GSC*10] and high school education in biomolecular life sciences [NSM*12].

In this paper, results of two consecutive years running a course in "Augmented Reality Interfaces" with postgraduate students at Masaryk University are presented. The aim of the task was to design and implement AR user interfaces for improving the learning

DOI: 10.2312/eged.20171025

process of explaining/describing difficult computer graphics principles. The main focus of this activity, was on concentrating on three aspects: interface design, interaction mediums and collaboration aspects. To the best of our knowledge this is the first time in the Czech Republic that learning for computer graphics by project development is applied in practice. Results clearly indicate that the proposed approach has produced good engagement, satisfaction and pass-rate while it is considered more difficult compared to traditional approaches.

The rest of the paper is structured as follows. Section 2 explains what ALL is and how it works. Section 3 presents the course in AR. Section 4 demonstrates examples from student work. Section 5 outlines the results including observations and feedback whereas section 6 presents the conclusions.

2. Activity Led Learning

ALL can be considered as an alternative option of similar teaching methods such as group-based learning [SMJ04], activity-centered design [Con11], trace-based teaching [HJ13], problem-based learning (PBL) [BFD05], learning by development [Rai13] and game-based learning [OCO13]. The range of activities and tasks has a wide range and according to the requirements, different activities have to be planned and disseminated.

One of the main characteristics of ALL (over its closely associated problem-based learning pedagogy) is to minimise or even eliminate contact hours with the educator [IJP*08], particularly in terms of coming up with solutions to a problem while simultaneously being a strong fit for practices such as groupwork assessments and student engagement, both of which comprise of large parts in a cutting-edge higher education curriculum. It is therefore ideal for employment in the programming/software development industry which can benefit from graduates with skills attuned to the previously mentioned transferable attributes and are prepared to work to the successful solutions of issues without costly supervision.

ALL can include a broad range of different formats and types of activities ranging from simple problem-based solving exercises to yearly projects. In other words, it is a pedagogy in which the activity is the focal point of the learning experience and the tutor acts as a facilitator. ALL requires a self-directed process in which the individual learner, or team of learners, seek and apply knowledge, skillful practices, resources (personal and physical) relevant to the activity being undertaken.

Such projects can bring new and unexpected areas for developing competences thus integrating the authenticity and complexity of real work in the learning process [Rai13]. Students have the opportunity to develop independent learning in challenging but supportive environment and enhance crucial skills for future employment such as collaboration, communication, creativity and social responsibility [BFD05]. On the other hand, collaboration has the potential of improving learning when teaching undergraduates on science [SSD99]. Individuals can benefit from this process by sharing their thoughts and ideas with other member of a group. A case-study in biology reported that students had similar mental models and knowledge pieces after collaborative learning and that the amount of collaborative knowledge was related to the amount of learning [JC97].

3. Teaching 'Augmented Reality Interfaces'

Masaryk University, located in Brno, is the second-largest public university in the Czech Republic and one of its top priorities is high quality teaching. The Human-Computer Interaction (HCI) Laboratory, the Department of Computer Graphics and Design, offers computer graphics courses such as: visualization, computer graphics, animation, human-computer interaction, advanced game design, virtual environments and augmented reality interfaces.

The "Augmented Reality Interfaces" course intends to introduce all major aspects of augmented reality such as the underlying hardware and software technologies as well as the most significant application domains. At the end of the course students are able to: (a) *demonstrate an understanding of the main mathematical concepts, hardware and software technologies used in augmented reality*; (b) *evaluate different approaches, methodologies and tools focused on augmented reality*; (c) *propose augmented reality environments for both indoor and outdoor environments*; and (d) *design multimodal augmented reality interfaces for various application domains*.

Each semester consists of 13 weeks activities and the course is offered to students of any study field. The only prerequisite is the knowledge of computer graphics fundamentals. The assessment is through a practical assignment and exams. The assignment included two parts: (a) the software implementation and (b) a report (where they explain how they did the design and implementation, the problems they faced as well as diagrams explaining the most significant aspects of their work). The first year 4 students were registered in the course and the second year 9 (13 in total for both years). Their educational background ranged from computer science to psychology and arts.

3.1. Requirements

Past research suggests that AR has potential to be effective in teaching complex 3D concepts [DWHB12]. The presentation of multimedia information in 3D allows for the exploration of spatial problems that are difficult to grasp in 2D media [WBL*04]. The aim of the assignment was to make use of an AR API to create an educational game/task focused on computer graphics theory. All types of multimedia information can be superimposed. Tracking should be focused on markers and single or multiple markers may be used.

Emphasis was given on the interaction and visualisation techniques and not on tracking techniques. The selection of the AR and graphics APIs was open to the students. AR interfaces offer the ability to use sophisticated techniques to achieve better user interaction with teaching material and complex tools [Lia12]. Students were instructed to follow specific design guidelines. In particular, the educational AR interface should fulfill at least the following requirements as illustrated in Figure 1.

3.2. Teaching methods

The overall strategy, was to present students with the theoretical background in AR according to the classical way and then ask them

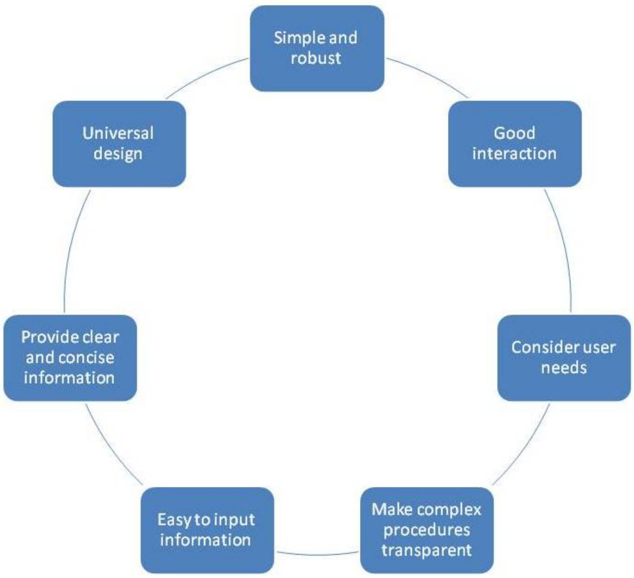

Figure 1: *AR Interface Requirements*

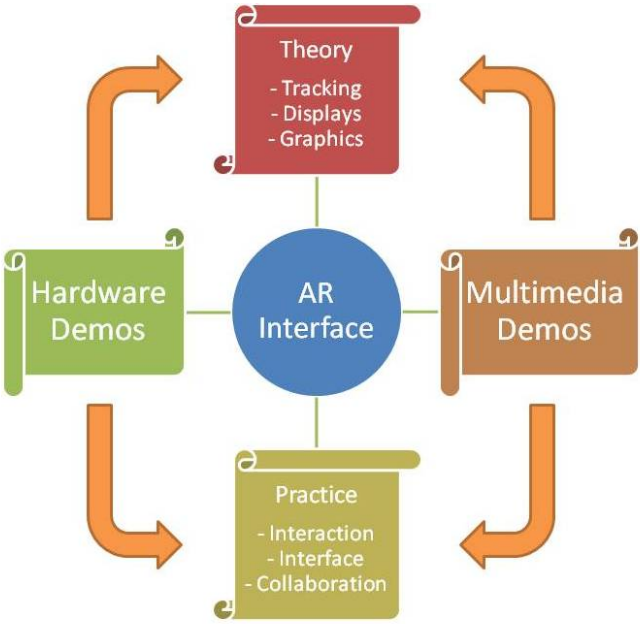

Figure 2: *Overview of the Teaching Approach*

to implement an AR educational interface for teaching computer graphics using ALL approaches. Emphasis was given on providing them with as much freedom as possible (in terms of design and implementation) to develop their own user interfaces. Active engagement allows students to construct knowledge and organize information into meaningful schema [May03]. Engagement is important because it contributes in activating knowledge structures [May05] and this is ideal for AR since it increases engagement of the students.

Figure 2 illustrates the main components of the teaching approach. In terms of the theory, 13 lectures (2 hour sessions) were delivered to the students on a weekly basis. The course covers areas such as: software APIs, displays, tracking, rendering, interaction, perception, application domains, collaboration and future directions. Lectures and practicals were supported by multimedia and hardware demonstrations. For example, relevant multimedia information supported the lectures, including live demos and videos of how different concepts of the AR technology work (i.e. collaboration, displays etc). Also, different application domains were presented including: education, navigation, archeology, interior design, military and medicine. Hardware demonstrations took place, illustrating to students various AR technologies such as head-mounted displays (HMDs), tracking devices (i.e. motion capturing) and interaction devices (ranging from simple devices like the Wii and Kinect to more advanced like brain-computer interfaces).

During the practical sessions students were allowed to experiment with the knowledge gained from both the theoretical lectures and demonstrations to design the AR Interface. Students were advised to select a topic in computer graphics that they found it difficult to understand (when studying it). They had to think and design their own scenarios (section 3.3). The objective was to concentrate on three aspects that were taught in the classroom including: interface design, interaction mediums and collaboration aspects. Students were not given any programming help on how to implement the various features of the assignment. The only assistance they received was basic theory regarding AR which was taught in the classroom. In addition to that, they had weekly meetings to report on their progress. This approach is very different from other practical sessions run at the Faculty of Informatics, which are following traditional approaches.

3.3. Scenarios

Engaging scenarios allow students to interact physically and intellectually with instructional learning material. In this context, students were asked to define their own scenarios based on [LA10]. An overview of the categories of the scenarios are presented in Figure 3. In theoretical tutorials only the most important aspects of the theory are described. The theoretical tutorials are the easiest to design technologically as no (or minimal) interaction is required. The instructor simply needs to present the appropriate information to the students. However, the toughest challenge is the representation of the information in an appropriate manner for understanding and learning.

The practical tutorials (which are based on the theory) describe a simple but complete process. Students have to use natural means (i.e. set of marker cards) to explore a complex process or system, such as understanding how computer graphics principles work (i.e. lighting) or how algorithms work (i.e. ray casting). Finally, the assessment tutorials aim to provide a less stressful way to evaluate the learning ability of the students. In the simplest scenario, students are provided with an augmentation of a 3D object or scene and a related question is asked. In more complex scenarios, AR

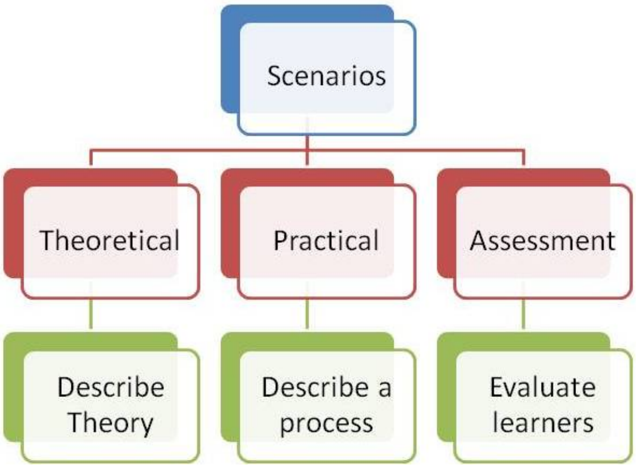

Figure 3: *Types of Scenarios Used in AR*

quizzes can present a sequence of questions and have the potential of creating an enjoyable method for assessing students.

4. Student Work

All scenarios were specifically engaged with the improvement of learning and teaching techniques in the fields of computer graphics. Emphasis was given in providing a rewarding learning experience that is otherwise difficult to obtain [Lia05]. Students were allowed to freely select topics from computer graphics. This section presents a selection of six postgraduate assignments presented during the past two academic years.

4.1. Ray Casting

The purpose of this assignment was to focus on rendering and computer graphics. Ray casting is one of the simplest rendering algorithms which makes use of ray/surface intersection tests to solve a variety of problems in computer graphics and computational geometry. Ray casting can refer to a variety of problems and techniques such as hidden surface removal algorithms and ray-tracing. The assignment was implemented in C++ using the following software libraries: Qt framework, ARToolKit [Artb] and FBX SDK [FBX].

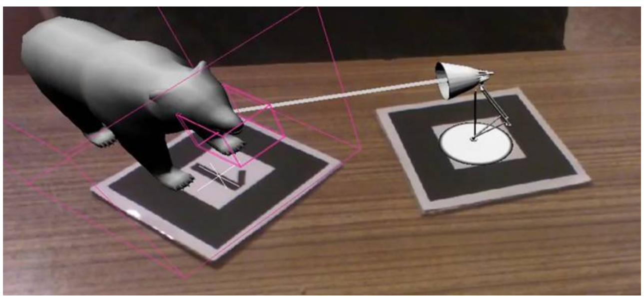

Figure 4: *AR Ray Casting Illustration*

Two basic algorithms were implemented and demonstrated: 'intersection of a plane and a line' and ' Point inside polygon'. Learners can make use of two markers, one which is casting rays and another one which superimposes a 3D object. In this way, they can interactively experience a real-time ray caster in a table-top AR environment as demonstrated in Figure 4.

4.2. Three-Dimensional Transformations

The purpose of this assignment was to briefly introduce 3D space transformations using transformation matrices. Focus was given on developing an AR educational application allowing user to manipulate these transformations. The implementation was developed in Kubuntu 16.10 operating system using Ogre3D graphics engine [OGR] and ARToolKit.

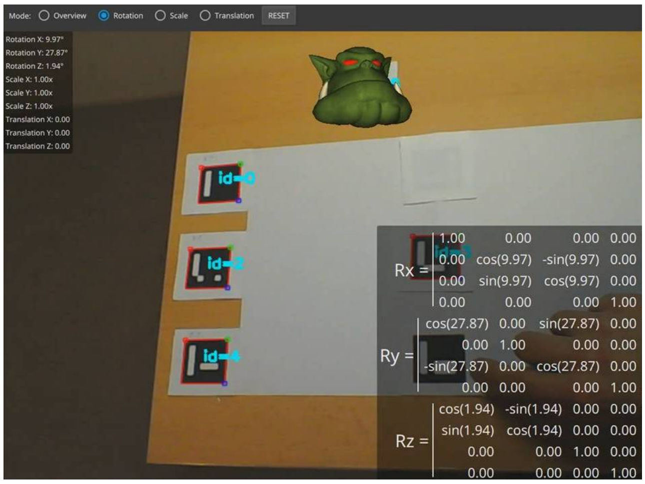

Figure 5: *AR Transformations Illustration*

An overview of how the interface works is presented in Figure 5. The learner can understand very fast how basic transformations work including: rotations, translations and scaling. There are respective markers for each operation and the numerical results of each transformation are presented in orthographic mode. A simple GUI is also implemented which allows the learner to specify a particular transformation or reset the scene.

4.3. Bézier Curves

Bézier curves are parametric curves, often used in computer graphics for modelling, animation and font creation [Bez66], [Bez67]. The reason of their extensive usage is primarily their quick construction, invariance towards affine transformations and also their intuitive control. To help the user understand the relationship between the curve and its parameter, a yellow sphere is rendered in the point that lies on the curve at a given parameter. For this application, the ARToolKit plug-in for Unity engine was used [Arta]. Figure 6 demonstrates how bézier curves can be visualised and experienced using four (movable) markers.

The user can manipulate the input parameter by a slider in the bottom right corner and thus indirectly affect the sphere's position,

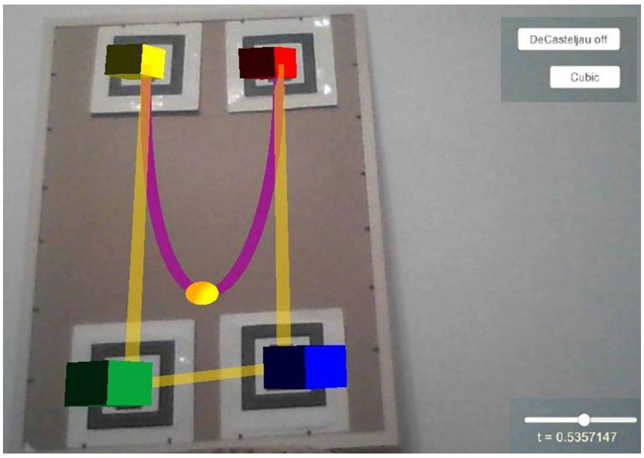

Figure 6: *AR Bézier Curves Illustration*

moving it along the curve, whatever its shape might be. The slider cannot be moved outside the parameter boundaries, so the input is always valid. The user can drag the markers around in the real world, changing the course of the on-screen rendered curve, and also select the degree of rendered curve, display a point in a particular parameter and toggle de Casteljau's algorithm visualisation on/off.

4.4. Fundamentals of Computer Graphics

The purpose of this assignment was to focus on interface design and human computer interaction to teach the basics of lighting (DirectLight, PointLight and SpotLight), shading (Transparent, Specular, Diffuse) and hard and soft shadows. Implementation was done in Unity using the ARToolKit plug-in. Figure 7 (top) illustrates the graphical user interface (GUI) and Figure 7 (bottom) illustrates spot light operation in AR. Digital information includes: images, 3D models, textual and audio relevant information. Ten different scenes exist, each one representing a different context (i.e. lighting, shading and shadows). The menu is mostly composed by GUI objects. When the user clicks into a button to another scene, the scoreboard increases by one point, but just once, multiple visits to a scene are not counted.

4.5. Texture Mapping

Flashcards provide a way to study and review learning material. The main principle is to have a series of boxes and cards containing question on one side and answer on another. User picks a card and tries to answer as good as they can. Then flips the card and looks at the answer. When the answer was correct they place the card into the next box. If answer was incorrect they place the card into previous or first box. The first box is to be reviewed most frequently while the latest box the least. New cards are placed into first box. This way the information is reviewed accordingly to user's ability to remember it. The implementation of the project was done based on Anki and ARToolKit plug-in for Unity engine. AR Flashcards was an implementation of spaced repetition technique similar to software Anki with AR interface. Project aims to help students learn texturing in an interactive way (Figure 8). AR interface takes advantage of superimposing 3D objects onto real environment which is a good fit for the area of computer graphics. In contrast to other AR flashcards, this project is not using a touch-screen device and is controlled purely by manipulating physical cards. Compared to Anki user needs more time to study same amount of cards when using AR Flashcards.

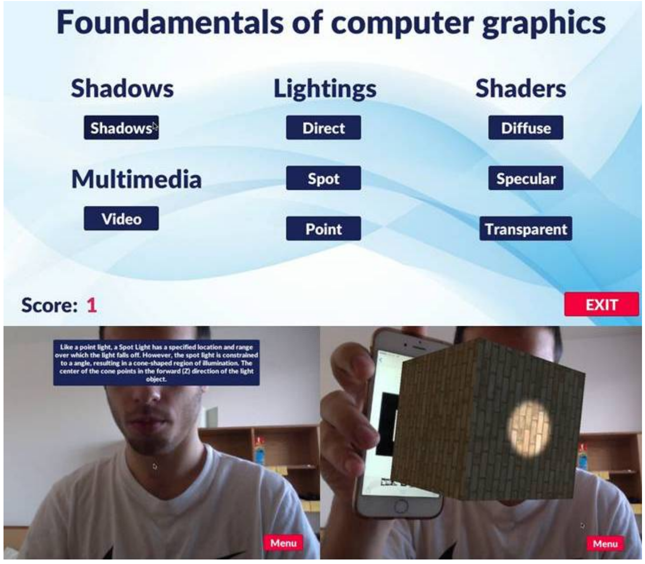

Figure 7: *GUI and AR Spot Light Illustration*

Figure 8: *AR Bump Mapping Illustration*

4.6. Image Effects

The output of this assignment was a multi-player game (Figure 9), in which players compete with each other trying to get the highest score by selecting the currently shown post-processes or image effects. The game starts by creating a hosting session by pressing the 'Host' button. The host can set the settings of the game, such as number of questions, difficulty (depending on the simultaneous effects) or activate/deactivate the action mode. The AR tracking was powered by Vuforia for Android, which uses image-based markers to calculate location and orientation of virtual objects. The application is developed in the Unity game engine with standard effects package and UNET networking feature.

Some of the effects that were implemented include: antialising,

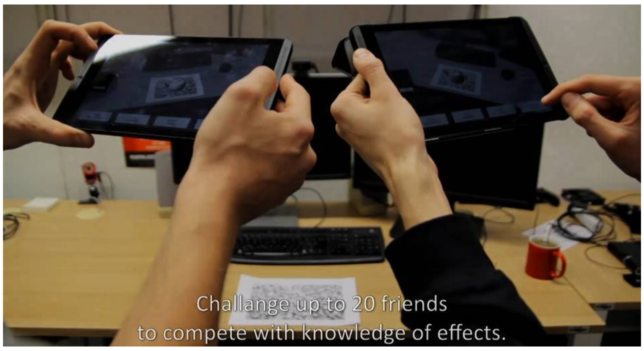

Figure 9: *AR Image Effects Game*

motion blur, fisheye, edge detection, noise and grain and vortex. When the game starts, the rendered image with both the camera feed and superimposed 3D model (if the marker is detected) is modified with a randomly selected post-process or image effect. All users see the see the same effects and possible answers. The user's task is to pick the active effect(s) by pressing one from four answer buttons. If action mode is not active, all players select the answer and press the "Ready" button on the top right corner of the screen, where player's score is among other things also shown.

5. Results

This section presents results based on personal observations and the University evaluation feedback.

5.1. Observations

The students generally appreciated the approach followed and delivered very interesting educational AR applications. They were motivated by the fact that they had to select a topic in computer graphics that they found it difficult to understand in the past. This allowed them to be creative during the design and implementation phase. They felt that they were not just performing the assignment in a routine like fashion, but actually accomplish it in a fun way. During the whole process the following observations were made:

- **Satisfaction**: All students have managed to finish their assignment at a satisfying level. This was a different result from previous teaching approaches, whereas there were cases that students could not complete their task.
- **Engagement**: Student engagement was very high. They seem to want to collaborate by themselves to show progress and get internal feedback. Also some students explored the possibilities of integrating their solution with a motion tracking system.
- **Design**: Students demonstrated different design skills. About one third of them did a more advanced GUI, whereas the rest of them did something very minimal.
- **Graphics**: The majority of the students used a game engine to implement the interface. This allowed them to spend more time on the actual design rather than on the implementation. Only a few tried to use lower level APIs such as OpenGL.
- **Collaboration**: Most of the students focused on basic collaboration techniques. Apart from the last presented project (section 4.6) which was a fully collaborative interface, the rest were only limited to marker manipulation.
- **Tutorials**: Those who followed 'practical tutorials' used Unity with ARToolKit plug-in as their main development platform. On the other hand, students who focused on 'theoretical tutorials' used C++ and ARToolKit (C version), whereas for students using 'assessment tutorials' employed Vuforia.
- **Learning**: Arts based students focused more on task based learning, trying to illustrate a particular part of the theory. They did not bother so much on the graphics quality. On the contrary, informatics students were focused more on implementing complete scenarios or even a complete game.

5.2. Feedback

The University records feedback for each course through anonymous questionnaires (accessed through the information system). The most relevant results from the past academic year (the first year there were no data) are presented here. In terms of qualitative feedback, students were given the following questions: In your opinion, what does the teacher excel in? What do you value most in their course or in their approach to teaching? Do you have any recommendations regarding the teacher's lessons or approach to teaching? The feedback recorded by 3 students was: "The teacher is friendly and forthcoming. He is very encouraging with regard to student initiative and ideas", "Very interesting course, I am glad that I took it. I have never imagined that creating an AR application would be so easy nowadays, and that I could do it myself" and "It was really interesting lecture, learned entirely new area of IT having lots of fun".

In terms of quantitative feedback Figure 10 illustrates a screenshot of the questions asked and the scores (compared with the Faculty's scores). Students were given clear instructions on how to respond using Likert scale (strongly agree = 1, agree = 2, somewhat agree = 3, somewhat disagree = 4, disagree = 5, strongly disagree = 6). In cases that no answer was provided, the answer was not included in calculating the mean values.

	Average Rating of the courses at the Faculty	Average Rating of the teacher of the course
The course is of educational value to me	2.2	1.0
The subject was very easy to complete	3.3	3.5
The teacher's presentation of the subject matter was always clearly intelligible	2.1	1.8
The teacher was always well prepared for the classes	1.7	1.2
The teacher provided clear information regarding the knowledge and skill that will be evaluated	1.9	1.2
The teacher is an excellent pedagogue and delivers great lectures	2.1	1.8

Figure 10: *Evaluation Results from the 2nd Year*

Although the sample responded was small (4 out of 9 students), results clearly indicate that there was educational value for the students compared to the traditional teaching approaches. Moreover, the ALL approach followed seems to be harder. This could be explained by the type of the assignment. Students had a task to complete which was specified by the instructor, but the individual aspects of the design were down to them to decide.

6. Conclusions

In this paper results from two consecutive academic years of student's assignments from a course focused on AR interfaces were presented. Although teaching was performed in the standard way, the assignment had strong ALL elements, allowing students to select different topics from computer graphics discipline. They had to think about the design, implementation and impact. Their aim was to implement a game/tool to assist future students to understand better a variety of computer graphics issues.

Initial results showed that: (a) *all students completed the assignment*; (b) *engagement and satisfaction was high*; and (c) *learning was fun but assignment was harder*. As demonstrated, that was not the case in other courses taught in the Faculty. A reason for that could be the fact that students had to be more creative. Every student followed a different design approach and in each case the outcome was at a high level. This was unexpected since students did not really try the easiest approach but they were challenged and motivated. Finally, it was shown that using current software tools it is easy and fast to develop AR learning applications that can actually help new students in their learning process.

Acknowledgments

The author would like to thank all the students of the Augmented Reality Interfaces course as well as the Human-Computer Interaction Lab members for their support and inspiration.

References

[AP09] ANDERSON E. F., PETERS C.: On the provision of a comprehensive computer graphics education in the context of computer games: An activity-led instruction approach. In *Proc. Eurographics'09, Education Papers* (2009), The Eurographics Association, pp. 7–14. doi:10.2312/eged.20091012. 1

[APH*12] ANDERSON E. F., PETERS C., HALLORAN J., EVERY P., SHUTTLEWORTH J., LIAROKAPIS F., LANE R., RICHARDS M.: In at the deep end: An activity-led introduction to first year creative computing. *Computer Graphics Forum 31*, 6 (2012), 1852–1866. doi:10.1111/j.1467-8659.2012.03066.x. 1

[Arta] ARTOOLKIT: Artoolkit plug-in for unity. URL: https://artoolkit.org/download-artoolkit-sdk. 4

[Artb] ARTOOLKIT: Open source augmented reality sdk. URL: https://artoolkit.org/. 4

[BBF*14] BACCA J., BALDIRIS S., FABREGAT R., GRAF S., KINSHUK: Augmented reality trends in education a systematic review of research and applications. *Educational Technology and Society 17*, 4 (2014), 133–149. 1

[BCS*16] BELLINI H., CHEN W., SUGIYAMA M., SHIN M., AKAM S., TAKAYAMA D.: Profiles in innovation, virtual and augmented reality: Understanding the race for the next computing platform, 2016. URL: http://www.goldmansachs.com/our-thinking/pages/technology-driving-innovation-folder/virtual-and-augmented-reality/report.pdf. 1

[Bez66] BEZIER P.: Denition numerique des courbes et surfaces i. *Automatisme XI* (1966), 625–632. 4

[Bez67] BEZIER P.: Denition numerique des courbes et surfaces ii. *Automatisme XII* (1967), 17–21. 4

[BFD05] BREITER A., FEY G., DRECHSLER R.: Project based learning in student teams in computer science education. *Electronics and Energetics 18*, 2 (2005), 165–180. 2

[Con11] CONSTANTINE L.: Activity-centered interaction design: a model-driven approach. In *Proc. of the 13th Int'l Conference on Human-Computer Interaction* (2011), vol. Part IV, pp. 696–697. 2

[DKEB15] DIEGMANN P., KRAEPELIN M. S., EYNDEN S. V. D., BASTEN D.: Benefits of augmented reality in educational environments - a systematic literature review. In *Proc. Wirtschaftsinformatik* (2015), pp. 1542–1556. 1

[DWHB12] DÜNSER A., WALKER L., HORNER H., BENTALL D.: Creating interactive physics education books with augmented reality. In *Proc. of the 24th Australian Computer-Human Interaction Conference* (2012), pp. 107–114. doi:10.1145/2414536.2414554. 2

[FBX] FBX: Fbx sdk - autodesk. URL: http://usa.autodesk.com/adsk/servlet/pc/item?siteID=123112&id=26012646. 4

[GSC*10] GUTIERREZ M. J., SAORIN J. L., CONTERO M., ALCANIZ M., LOPEZ D. C. P., ORTEGA M.: Education: Design and validation of an augmented book for spatial abilities development in engineering students. *Computers and Graphics 34*, 1 (2010), 77–91. doi:10.1016/j.cag.2009.11.003. 1

[HJ13] HERTZ M., JUMP M.: Trace-based teaching in early programming courses. In *Proc. of the 44th ACM Technical Symposium on Computer Science Education* (2013), pp. 561–566. doi:10.1145/2445196.2445364. 2

[IJP*08] IQBAL R., JAMES A., PAYNE L., ODETAYO M., AROCHENA H.: Moving to activity-led-learning in computer science. In *Proc. of iPED International Conference* (2008). 2

[JC97] JEONG H., CHI M. T. H.: Construction of shared knowledge during collaborative learning. In *Proc. of the 2nd International Conference on Computer support for collaborative learning* (1997), pp. 130–134. 2

[KS03] KAUFMANN H., SCHMALSTIEG D.: Mathematics and geometry education with collaborative augmented reality. *Computers and Graphics 27*, 3 (2003), 339–345. doi:http://dx.doi.org/10.1016/S0097-8493(03)00028-1. 1

[LA10] LIAROKAPIS F., ANDERSON E. F.: Augmented reality as a medium to assist teaching in higher education. In *Proc. Eurographics'10, Education Papers* (2010), The Eurographics Association, pp. 9–16. doi:10.2312/eged.20101010. 1, 3

[Lia05] LIAROKAPIS F.: *Augmented Reality Interfaces - Architectures for Visualising and Interacting with Virtual Information*. University of Sussex, PhD Thesis, 2005. 1, 4

[Lia12] LIAROKAPIS F.: Augmented reality interfaces for assisting computer games university students. *Bulletin of the Technical Committee on Learning Technology 14*, 4 (2012). 1, 2

[May03] MAYER R. E.: The promise of multimedia learning: using the same instructional design methods across different media. *Learning and Instruction 13*, 2 (2003), 125–139. doi:http://dx.doi.org/10.1016/S0959-4752(02)00016-6. 3

[May05] MAYER R. E.: *The Cambridge handbook of multimedia learning*. New York: Cambridge University Press, 2005. 3

[NSM*12] NICKELS S., SMINIA H., MUELLER S. C., KOOLS B., DEHOF A. K., LENHOF H. P., HILDEBRANDT A.: Proteinscanar - an augmented reality web application for high school education in biomolecular life sciences. In *Proc. 16th Int'l Conference on Information Visualisation* (2012), IEEE Computer Society, pp. 578–583. doi:10.1109/IV.2012.97. 1

[OCO13] OZCELIK E., CAGILTAY N. E., OZCELIK N. S.: The effect of uncertainty on learning in game-like environments. *Computers and Education 67* (2013), 12–20. doi:http://dx.doi.org/10.1016/j.compedu.2013.02.009. 2

[OGR] OGRE: Ogre - open source 3d graphics engine. URL: http://www.ogre3d.org/. 4

[Rai13] RAIJ K.: Learning by developing in higher education. *Journal of Education Sciences*, 2 (2013), 6–21. 2

[SMJ04] STRIJBOS J. W., MARTENS R. L., JOCHEMS W. M. G.: Designing for interaction: Six steps to designing computer-supported group-based learning. *Computers and Education 42*, 4 (2004), 403–424. doi:http://dx.doi.org/10.1016/j.compedu.2003.10.004. 2

[SSD99] SPRINGER L., STANNE M. E., DONOVAN S. S.: Effects of small-group learning on undergraduates in science, mathematics, engineering, and technology: A meta-analysis. *Review of Educational Research 69*, 1 (1999), 21–51. doi:10.3102/00346543069001021. 2

[WBL*04] WOODS E., BILLINGHURST M., LOOSER J., ALDRIDGE G., BROWN D., GARRIE B., NELLES C.: Augmenting the science centre and museum experience. In *Proc. of the 2nd Int'l Conference on Computer Graphics and Interactive Techniques in Australasia and South East Asia (GRAPHITE '04)* (2004), ACM Press, pp. 230–236. doi:10.1145/988834.988873. 2

[YYJ11] YUEN S., YAOYUNEYONG G., JOHNSON E.: Augmented reality: An overview and five directions for ar in education. *Journal of Educational Technology Development and Exchange 4*, 1 (2011), 119–140. 1