J Sci Educ Technol (2015) 24:119–124
DOI 10.1007/s10956-014-9526-4

ARBOOK: Development and Assessment of a Tool Based on Augmented Reality for Anatomy

J. Ferrer-Torregrosa · J. Torralba · M. A. Jimenez · S. García · J. M. Barcia

Published online: 31 October 2014

Abstract The evolution of technologies and the development of new tools with educational purposes are growing up. This work presents the experience of a new tool based on augmented reality (AR) focusing on the anatomy of the lower limb. ARBOOK was constructed and developed based on TC and MRN images, dissections and drawings. For ARBOOK evaluation, a specific questionnaire of three blocks was performed and validated according to the Delphi method. The questionnaire included motivation and attention tasks, autonomous work and three-dimensional interpretation tasks. A total of 211 students from 7 public and private Spanish universities were divided in two groups. Control group received standard teaching sessions supported by books, and video. The ARBOOK group received the same standard sessions but additionally used the ARBOOK tool. At the end of the training, a written test on lower limb anatomy was done by students. Statistically significant better scorings for the ARBOOK group were found on attention–motivation, autonomous work and three-dimensional comprehension tasks. Additionally, significantly better scoring was obtained by the ARBOOK group in the written test. The results strongly suggest that the use of AR is suitable for anatomical purposes. Concretely, the results indicate how this technology is helpful for student motivation, autonomous work or spatial interpretation. The use of this type of technologies must be taken into account even more at the present moment, when new technologies are naturally incorporated to our current lives.

Keywords Anatomy · Augmented reality · Three-dimensional interpretation · Teaching-supporting material · Virtual imaging

J. Ferrer-Torregrosa · J. Torralba
Department of Physiotherapy and Podiatry, Catholic University of Valencia "San Vicente Mártir", Valencia, Spain

M. A. Jimenez
Department of Educational Sciences, Catholic University of Valencia "San Vicente Mártir", Valencia, Spain

S. García
Department of Health Xativa-Ontinent, Health Agency of Valencia, Valencia, Spain

J. M. Barcia (✉)
Department of Anatomy, Faculty of Medicine and Dentistry, Catholic University of Valencia "San Vicente Mártir", C/Quevedo 2, 46001 Valencia, Spain
e-mail: jbarciamonster@gmail.com

Introduction

Three-dimensional visualization of anatomical structures is one of the most challenging aspects on teaching–learning process. Not only for students but also for instructors, three-dimensional representation usually implies some training. In this sense, plastic models or cadaveric demonstrations are helpful in order to achieve spatial interpretation of structures. Nowadays, the advance of new electronic media has led to a deep revolution in the way we observe the human body. Technologies allow us to observe three-dimensional images of internal organs in standard Smartphones. Despite some reports did not support the benefits of these advances (Garg et al. 1999, 2001, 2002), many others confirmed the effectiveness of these new technologies for students (Harman et al. 1999; James et al. 2001, 2002; McLachlan et al. 2004; Stirling and Birt 2014).

In order to improve teaching–learning process in anatomical sciences, instructors reinforce their lectures with several tools, using from plastic or wax models to cadaveric pieces (Vernon and Peckham 2002). Seminars or practical sessions are also included in biomedical curricula in order to achieve spatial comprehension of anatomical structures. Traditionally, these classical forms of teaching used to be performed in small groups pretending a customized instruction. Although real cadaver or synthetic models are irreplaceable tools for comprehension of structures, those present inconveniences in terms of price, location, portability or legacy. These tools can be only found in laboratories, workshops or classrooms and with limited access for students. Even more, reducing the number of students in seminars or practical workshops evidently implicates more qualified supervisor staff. Considering these previous points and the time spent by students in terms of autonomous work or group work, the use of these technologies could be part of the solution of the aforementioned problems. In this sense, and according to the new technologies, innovative techniques have been also targeted on surgery training (Cottam 1999; Luursema et al. 2006; Keehner et al. 2008).

One relevant aspect for learning process is that related to motivation. Motivation includes reciprocal interactions among environmental contexts, behaviors and personal characteristics (Bandura 1986, 2001; Bryan et al. 2011). This self-regulated process improves when students assume conscious control over their motivation and behavior in a way which leads to desirable learning outcomes (Glynn et al. 2011). The motivation to learn science is defined as an internal state that maintains science-learning behavior (Eccles and Wigfield 2002; Glynn et al. 2011; Campos-Sánchez et al. 2014), and for this reason, the development of tools promoting motivation and self-learning is widely justified.

Based on three-dimensional imaging and of interest for biomedical/technical sciences, the augmented reality (AR) is considered as a variant of the virtual reality (VR) (Azuma et al. 2001). The revolutionary innovation of AR is the overlapping of actual surrounding environment with virtual images. In fact, the use of VR/AR has been previously reported as useful for students (Nicholson et al. 2006; Sakellariou et al. 2009; Lamounier et al. 2010; Thomas et al. 2010; Luciano et al. 2011). AR is currently used not only for surgery training but also for intraoperative guidance (Cabrilo et al. 2014; Okamoto et al. 2014; Soler et al. 2014).

Although motivation or skill achievement is the most important target for the development of teaching tools, other factors such as portability, price and student autonomy must also be considered. We present herein results obtained after using the augmented reality book (ARBOOK) as supporting teaching tool. ARBOOK was developed at UCV by staff professors in collaboration with LabHuman® from Polytechnic University of Valencia (UPV) and visual medical 3D company (VMV3D®).

Materials and Methods

Development of the Tool: "Augmented Reality Book (ARBOOK) Part I. Lower limb"

ARBOOK can be presented in both, printed or electronic version. ARBOOK includes a standard part of descriptive anatomy of the lower limb including osteology, arthrology, myology, nerve and vascular supply. Each part of the book includes bi-dimensional images and text about the muscles: origin insertion, vascular and nerve supply or action (see Fig. 1a).

The ARBOOK includes a card (Fig. 1b) for each anatomical figure that can be recognized by a digital webcam connected to a computer (see Fig. 1c, d). Then, the virtual AR image appears in the computer screen. The users can modify the actual position of the virtual structure by moving the card (Fig. 1d). A demonstration of the tool can be seen at the attached file (file 1).

To develop the ARBOOK, more than 100 TC images were needed and the images were processed by OsiriX® software and 3D constructed. LabHuman® and VMV3D® companies performed the animation.

Questionnaire: Development and Validation

After considering previous questionnaires, a specific questionnaire was needed to be developed because none of the questionnaire found achieved the scope of this new tool.

The questionnaire included 15 questions organized in 3 blocks.

The first block consists of eight items focused on motivation and attention tasks.

The second block consists of three questions related to the autonomous work. The third block consisted of five questions, dealing with the spatial comprehension–orientation and three-dimensional interpretation. For complete information of contents, see tables.

Responses were based on a four choices Likert scale (Never, Rarely, Frequently, Always). For statistical analysis, chi-square test was used and response categories were reduced to Yes/Not: Yes (Frequently + Always); not (Never + Rarely).

The validation of the questionnaire was performed according to the Delphi method (Dalkey and Helmer 1963). Three phases were done: preliminary, exploratory and final. Briefly, after defining items and structure, this first version was evaluated by expertise panel and feedback was

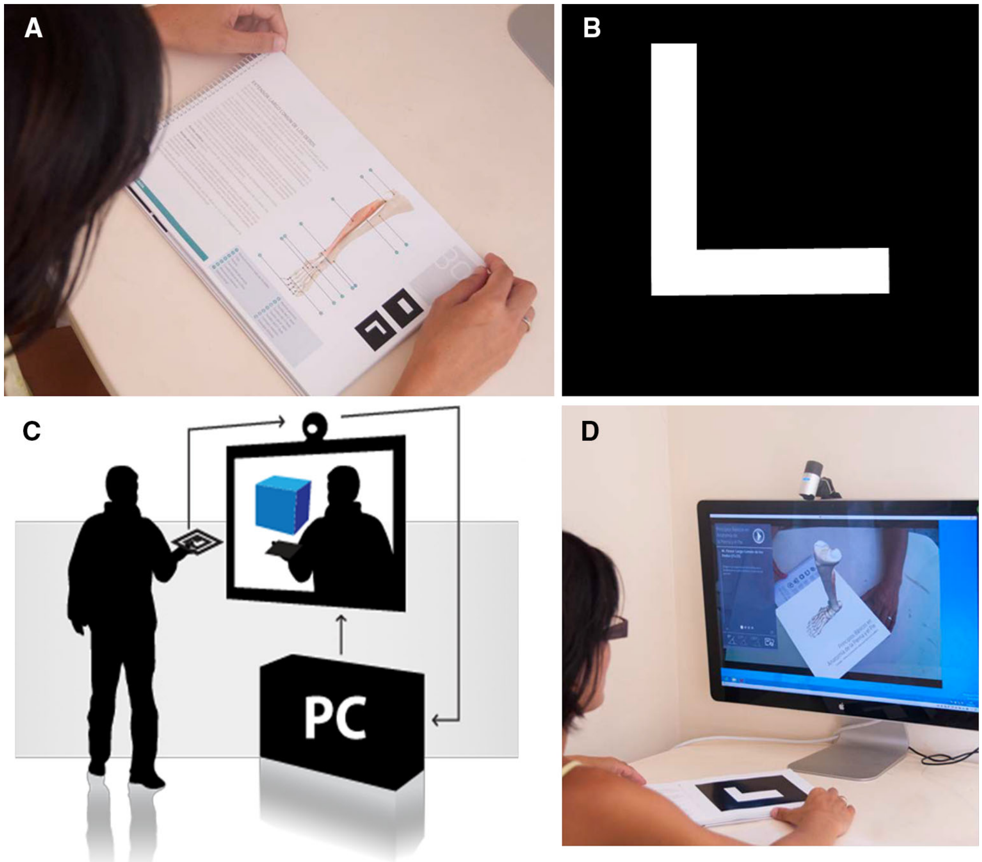

Fig. 1 Final aspect of the book ARBOOK. For each anatomical region, information about the anatomical structures is provided (origin insertion, neurovascular supply and action) (**a**). Additionally, a card is included on each section (**b**). The card is recognized by the PC camera and shown in the screen (**c**). The movement of the card is accompanied by movements on the virtual image (**d**)

included in the questionnaire for two cycles. Cronbach́s alpha was used to determine the internal consistence of the questionnaire.

Study of ARBOOK

Subjects, Recruitment and Inclusion Criteria

Students of anatomy were invited to participate. All Spanish universities were called to participate in this project. The initial requirements were: First year student, student of anatomy that never had studied before this subject. Second year students were excluded. Students with previous studies as Medicine, Physiotherapy, Nursing, Podiatry, etc., were also excluded. Students were randomly assigned to the Control group or the group named as ARBOOK.

The Control group received standard sessions with lectures, slides, and video recordings of cadaveric material. The ARBOOK group received the same standard sessions but additionally used the ARBOOK tool. Due to the technical requirements and novelty of the tool, the ARBOOK group was assayed in two universities.

A total of 211 students from 7 public and private Spanish universities agreed to participate in the ARBOOK project along the academic year 2012–2013. Forty-two participants were excluded according with any of the exclusion criteria.

About 134 students with a range of age between 18 and 41 years of age were assigned as Control group, and 77 students between 18 and 42 years were assigned as ARBOOK group. The distribution of gender was of 38, 8 % male and 61, 1 % female in the Control group. The ARBOOK group consisted of 33, 77 % male and 66, 23 % female.

A presentation letter within the aim of the study, instructions and material of the ARBOOK project was sent to the staff instructors. The project also included a virtual platform where the ARBOOK researchers could interact with students and get feedback or tutorials. All the materials used by both groups were uploaded to a virtual application, so the users could download it along the duration of the sessions. Once the sessions were finished,

Table 1 Frequencies (F) and percentages (%) of response on attention and motivation-related tasks from control and ARBOOK groups

Block I Attention and motivation The supporting material…		Control		ARBOOK		Chi-square		
		Yes	Not	Yes	Not	Value	*df*	*p* value
1. Is helpful to paying attention	F	94	40	72	5	15.9	1	0.000*
	%	70.2	29.8	93.5	6.5			
2. Is helpful to remember contents	F	95	39	67	10	7.125	1	0.008*
	%	71	29.1	87	13			
3. Motivates learning	F	90	44	66	11	8.731	1	0.003*
	%	67.2	32.8	85.7	14.3			
4. Allows to study on different ways	F	94	40	61	16	2.064	1	0.151
	%	70.1	29.8	79.2	20.8			
5. Is helpful to imagine the structures	F	104	30	74	3	12.67	1	0.000*
	%	77.6	22.4	96.1	4			
6. Is helpful to understand the lower limb biomechanics	F	88	46	66	11	9..963	1	0.002*
	%	65.7	34.3	85.7	14.3			
7. Is helpful to understand contents without indications of the professor	F	73	61	53	24	4.188	1	0.041*
	%	54.5	45.5	68.8	31.2			
8. Stimulates proactive learning	F	93	41	67	10	8.284	1	0.004*
	%	69.4	30.6	87	13			

Yes (Frequently + Always); not (Never + Rarely)

* $p < 0.05$

Table 2 Frequencies (F) and percentages (%) of response on autonomous work-related tasks from Control and ARBOOK groups

Block II Autonomous work The supporting material…		Control		ARBOOK		Chi-square		
		Yes	Not	Yes	Not	Value	*df*	*p* value
9. Is helpful to study and review contents by myself	F	98	36	65	12	3.541	1	0.600
	%	73.2	26.8	84.4	15.6			
10. Promotes my autonomous work	F	92	42	65	12	6.377	1	0.012*
	%	68.6	31.4	84.4	15.6			
11. Could be used to repeat the activities done in the classroom for myself as homework	F	81	53	67	19	16.48	1	0.000*
	%	60.5	39.5	85.3	14.7			
	%	65.7	34.3	39	61			

Yes (Frequently + Always); not (Never + Rarely)

* $p < 0.05$

the application was closed and all the students responded to the online questionnaire. Additionally, they were also individually assessed by a short written test on anatomical questions including two identification slides (with eight structures) and eight multiple choice questions about the lower limb. The global score of the test was of ten points.

Results

The questionnaire on the block I, focused on attention and motivation tasks, showed statistically significant differences of almost all questions but not the question number 4 (see Table 1). Percentages on Table 1 confirmed how this difference between groups reflects a better scoring for the ARBOOK group.

The block II (see Table 2) deals with three questions concerning autonomous work. The questions 10 and 11 showed statistically significant differences between groups indicating that ARBOOK group responded better to this task than the Control group. No differences between groups could be set for the question number 9.

Three-dimensional comprehension task was assessed on block III by five questions related with the anatomy and

Table 3 Frequencies (F) and percentages (%) of response on three-dimensional comprehension related tasks from Control and ARBOOK groups

Block III Three-dimensional comprehension The supporting material…		Control		ARBOOK		Chi-square		
		Yes	Not	Yes	Not	Value	*df*	*p* value
12. Makes me understand lower limb movements	F	87	47	68	9	14	1	0.000*
	%	64.9	35.1	88.3	11.7			
13. Makes me understand the anatomy of the lower limb	F	82	52	67	10	15.71	1	0.000*
	%	61.2	38.8	87	13			
14. Makes me understand muscular movements	F	88	46	71	6	18.54	1	0.000*
	%	65.7	34.3	92	7.8			
15. Makes me see the muscular movements	F	99	35	56	21	0.033	1	0.855
	%	73.9	26.1	72.7	27.3			

Yes (Frequently + Always); not (Never + Rarely)

* $p < 0.05$

movements of the lower limb (see Table 3). Although no differences between groups could be set on question 15, the questions 12, 13 and 14 presented statistically significant differences between groups indicating that ARBOOK facilitates spatial comprehension of structures and their actions.

A short test was included in the study in order to identify whether ARBOOK could result in a better test performance. The test included seven multiple choice questions and two figures with eight items to identify. The score (mean $\pm$ SD) for the Control group was 7.21 ± 1.73 points and 8.34 ± 1.64 points for the ARBOOK group. Although the results found are so close, statistically significant differences between groups could be found indicating better outcome for the ARBOOK group ($p = 0.0001$).

Discussion

Some considerations must be taken into account before discuss the results found herein. First of all, is that related to the achievement of the ARBOOK tool. More than 2 years were used to develop the ARBOOK project. A multidisciplinary work including anatomical educators, medical imaging professionals, image engineering and informatics was needed to develop this project. The other novelty was the necessity to develop a questionnaire fitting to the scope of ARBOOK and its repercussion on learning: Does AR facilitate anatomical study? A total of 29 professionals (among educationists and professors) participated on the development of the questionnaire and three cycles of revisions were needed for the final questionnaire achievement.

The ARBOOK group was only represented by two universities, whereas the Control group was represented by five universities. Obviously, the desirable distribution is the equal representation of both groups from each university participating in the study.

Fitting with others, indicating that the inclusion of virtual material in anatomical training may benefit student outcome (McNulty et al. 2004; Gopal et al. 2010; Stirling and Birt 2014). Additionally, ARBOOK is significantly better than conventional methods promoting motivation and autonomy. This is one of the most interesting points after considering the time spent by students in terms of autonomous work. The development of tools promoting self-learning and autonomous work must be seriously considered for anatomical training and other sciences.

In view of the results found on the block III, ARBOOK seems to improve spatial comprehension better than standard methods. Surprisingly, on item 15 referred to "see muscular movements," no differences could be set between groups, whereas significant differences can be found on item 14 "to understand muscular movement." Maybe the interpretation of "to see" and "to understand" leads students to confusion.

ARBOOK group got better scores on the individual written test than the Control group. This also fits with the results obtained on questionnaires, suggesting that ARBOOK may be helpful for students. However, more studies must be addressed in order to assess other unexplored possibilities of the ARBOOK tool.

According to the advance of new technologies and electronic devices, the academic methodologies must be changed. Agreeing with the results found herein, it has been recently presented an enriched book with good results on anatomy learning, known as "e-Book" (Stirling and Birt 2014). Additionally, interactive methodologies have also improved anatomy performances (McNulty et al. 2004; Gopal et al. 2010). Considering the benefits of the interactive and virtual methodologies for spatial comprehension, motivation and finally improving learning, new technologies can additionally be helpful to facilitate autonomous work and secondarily to reduce laboratory material and supervisor staff costs.

Two years ago appeared a revolutionary teaching device: The first virtual dissection table developed by Anatomage Inc. After considering the possibilities of AR and others, it is not far-fetched to imagine a future based on virtual imaging in classrooms. Independently that the real cadaver study never will be replaced, the incorporation of new teaching tools is also leading us to new ways of learning, extending theaters, classrooms or laboratories beyond the physical limits of the university campus.

References

Azuma R, Baillot Y, Behringer R et al (2001) Recent advances in augmented reality. Comput Graph Appl IEEE 21:34–47. doi:10.1109/38.963459

Bandura A (1986) Social foundations of thought and action: a social cognitive theory. Prentice-Hall, Englewood Cliffs

Bandura A (2001) Social cognitive theory: an agentive perspective. Annu Rev Psychol 14:1–26. doi:10.1146/annurev.psych.52.1.1

Bryan RR, Glynn SM, Kittleson JM (2011) Motivation, achievement, and advanced placement intent of high school students learning science. Sci Educ 14:1049–1063. doi:10.1002/sce.20462

Cabrilo I, Sarrafzadeh A, Bijlenga P, Landis BN, Schaller K (2014) Augmented reality-assisted skull base surgery. Neurochirurgie. doi:10.1016/j.neuchi.2014.07.001

Campos-Sánchez A, López-Núñez JA, Carriel V, Martín-Piedra MÁ, Sola T, Alaminos M (2014) Motivational component profiles in university students learning histology: a comparative study between genders and different health science curricula. BMC Med Educ 10(14):46. doi:10.1186/1472-6920-14-46

Cottam WW (1999) Adequacy of medical school gross anatomy education as perceived by certain postgraduate residency programs and anatomy course directors. Clin Anat 12:55–65

Dalkey N, Helmer O (1963) An experimental application of the Delphi method to the use of experts. Manag Sci 9:458–467

Eccles JS, Wigfield A (2002) Motivational beliefs, values, and goals. Annu Rev Psychol 14:109–132. doi:10.1146/annurev.psych.53.100901.135153

Garg A, Norman GR, Spero L, Maheshwari P (1999) Do virtual computer models hinder anatomy learning? Acad Med 74:S87–S89

Garg AX, Norman G, Sperotable L (2001) How medical students learn spatial anatomy. Lancet 357:363–364

Garg AX, Norman GR, Eva KW et al (2002) Is there any real virtue of virtual reality? The minor role of multiple orientations in learning anatomy from computers. Acad Med 77:S97–S99

Glynn SM, Brickman P, Armstrong N, Taasoobshirazi G (2011) Science motivation questionnaire II: validation with science majors and nonscience majors. J Res Sci Teach 14:1159–1176. doi:10.1002/tea.20442

Gopal T, Herron SS, Mohn RS et al (2010) Effect of an interactive web-based instruction in the performance of undergraduate anatomy and physiology lab students. Comput Educ 55:500–512

Harman KL, Humphrey GK, Goodale MA (1999) Active manual control of object views facilitates visual recognition. Curr Biol 9:1315–1318

James KH, Humphrey GK, Goodale MA (2001) Manipulating and recognizing virtual objects: where the action is. Can J Exp Psychol Can Psychol Exp 55:111–120

James KH, Humphrey GK, Vilis T et al (2002) "Active" and "passive" learning of three-dimensional object structure within an immersive virtual reality environment. Behav Res Methods Instrum Comput 34:383–390

Keehner M, Khooshabeh P, Hegarty M (2008) Individual differences among users: Implications for the design of 3D medical visualizations. User Centered Des Med Vis pp 1–24

Lamounier E, Bucioli A, Cardoso A et al (2010) On the use of Augmented Reality techniques in learning and interpretation of cardiologic data. Conf Proc Annu Int Conf IEEE Eng Med Biol Soc IEEE Eng Med Biol Soc Conf 2010:610–613. doi:10.1109/IEMBS.2010.5628019

Luciano CJ, Banerjee PP, Bellotte B et al (2011) Learning retention of thoracic pedicle screw placement using a high-resolution augmented reality simulator with haptic feedback. Neurosurgery 69:ons14. doi:10.1227/NEU.0b013e31821954ed

Luursema J-M, Verwey WB, Kommers PA et al (2006) Optimizing conditions for computer-assisted anatomical learning. Interact Comput 18:1123–1138

McLachlan JC, Bligh J, Bradley P, Searle J (2004) Teaching anatomy without cadavers. Med Educ 38:418–424

McNulty JA, Halama J, Espiritu B (2004) Evaluation of computer-aided instruction in the medical gross anatomy curriculum. Clin Anat N Y N 17:73–78

Nicholson DT, Chalk C, Funnell WRJ, Daniel SJ (2006) Can virtual reality improve anatomy education? A randomised controlled study of a computer-generated three-dimensional anatomical ear model. Med Educ 40:1081–1087

Okamoto T, Onda S, Yanaga K, Suzuki N, Hattori A (2014) Clinical application of navigation surgery using augmented reality in the abdominal field. Surg Today (in press)

Sakellariou S, Ward BM, Charissis V et al (2009) Design and Implementation of Augmented Reality Environment for Complex Anatomy Training: Inguinal Canal Case Study. Springer, San Diego, pp 605–614

Soler L, Nicolau S, Pessaux P, Mutter D, Marescaux J (2014) Real-time 3D image reconstruction guidance in liver resection surgery. Hepatobiliary Surg Nutr 3(2):73–81. doi:10.3978/j.issn.2304-3881.2014.02.03

Stirling A, Birt J (2014) An enriched multimedia eBook application to facilitate learning of anatomy. Anat Sci Educ 7:19–27. doi:10.1002/ase.1373

Thomas RG, William John N, Delieu JM (2010) Augmented reality for anatomical education. J Vis Commun Med 33:6–15

Vernon T, Peckham D (2002) The benefits of 3D modelling and animation in medical teaching. J Vis Commun Med 25:142–148