Augmented reality in healthcare education: an integrative review

Background. The effective development of healthcare competencies poses great educational challenges. A possible approach to provide learning opportunities is the use of augmented reality (AR) where virtual learning experiences can be embedded in a real physical context. The aim of this study was to provide a comprehensive overview of the current state of the art in terms of user acceptance, the AR applications developed and the effect of AR on the development of competencies in healthcare. **Methods.** We conducted an integrative review. Integrative reviews are the broadest type of research review methods allowing for the inclusion of various research designs to more fully understand a phenomenon of concern. Our review included multi-disciplinary research publications in English reported until 2012. **Results.** 2529 research papers were found from ERIC, CINAHL, Medline, PubMed, Web of Science and Springer-link. Three qualitative, 20 quantitative and 2 mixed studies were included. Using a thematic analysis, we've described three aspects related to the research, technology and education. This study showed that AR was applied in a wide range of topics in healthcare education. Furthermore acceptance for AR as a learning technology was reported among the learners and its potential for improving different types of competencies. **Discussion.** AR is still considered as a novelty in the literature. Most of the studies reported early prototypes. Also the designed AR applications lacked an explicit pedagogical theoretical framework. Finally the learning strategies adopted were of the traditional style 'see one, do one and teach one' and do not integrate clinical competencies to ensure patients' safety.

AUGMENTED REALITY IN HEALTHCARE EDUCATION: AN INTEGRATIVE REVIEW

Egui Zhu[1], Italo Masiello[1], Arash Hadadgar[1], Nabil Zary[1*]

[1]Department of Learning, Informatics, Management and Ethics (LIME), Karolinska Institutet, Stockholm Sweden

* Corresponding author

Nabil Zary
Karolinska Institutet
Department of LIME
Tomtebodavägen 18A, 17177 Stockholm, Sweden
Tel. +46 852487129
Email. Nabil.Zary@ki.se

Abstract

Background. The effective development of healthcare competencies poses great educational challenges. A possible approach to provide learning opportunities is the use of augmented reality (AR) where virtual learning experiences can be embedded in a real physical context. The aim of this study was to provide a comprehensive overview of the current state of the art in terms of user acceptance, the AR applications developed and the effect of AR on the development of competencies in healthcare.
Methods. We conducted an integrative review. Integrative reviews are the broadest type of research review methods allowing for the inclusion of various research designs to more fully understand a phenomenon of concern. Our review included multi-disciplinary research publications in English reported until 2012.
Results. 2529 research papers were found from ERIC, CINAHL, Medline, PubMed, Web of Science and Springer-link. Three qualitative, 20 quantitative and 2 mixed studies were included. Using a thematic analysis, we've described three aspects related to the research, technology and education. This study showed that AR was applied in a wide range of topics in healthcare education. Furthermore acceptance for AR as a learning technology was reported among the learners and its potential for improving different types of competencies.
Discussion. AR is still considered as a novelty in the literature. Most of the studies reported early prototypes. Also the designed AR applications lacked an explicit pedagogical theoretical framework. Finally the learning strategies adopted were of the traditional style 'see one, do one and teach one' and do not integrate clinical competencies to ensure patients' safety.

1. Introduction

Augmented reality (AR) supplements the real world with virtual objects that appear to coexist in the same space as the real world (Zhou, Duh, & Billinghurst, 2008). It has the potential to provide both powerful contextual, situated learning experiences and to aid exploration of the connected nature of information in the real world. Students can use it to construct new understanding based on interactions with virtual objects that bring underlying data to life. AR is being applied across disciplines in higher education including environmental sciences, ecosystems, language, chemistry, geography and history (Johnson, Smith, Willis, Levine, & Haywood, 2011; Klopfer & Squire, 2007). Clinical care is also interested in AR because it provides doctors with an internal view of the patient without the need for invasive investigations (Bajura, Fuchs, & Ohbuchi, 1992; Chris, 2010; De Paolis, Ricciardi, Dragoni, Aloisio, & Paolis, 2011; Lucio T. De Paolis, Pulimeno, & Aloisio, 2008; Pandya, Siadat, & Auner, 2005). There is clearly a need to further study the use of AR in healthcare education since students need more situational experiences and for the sake of patient safety (*Figure 1 and Figure 2*). AR has generated a wide interest over recent years (Rolland, 2003; Sielhorst, Obst, Burgkart, Riener, & Navab, 2004; Thomas, John, & Delieu, 2010) and the following aspects of AR have been highlighted:

- AR provides rich contextual learning for medical student achieving core competencies such as decision making, effective teamwork and creative adaptation of global resources to address local priorities(Frenk J, Chen L, Bhutta ZA, 2010).
- Provides opportunities for more authentic learning and appeals to multiple learning styles with their own unique discovery path
- The patients' safety is safeguarded if mistakes are made during skills training.

Figure 1. ProMIS Augmented Reality laparoscopic simulator (S. Botden, Buzink, Schijven, & Jakimowicz, 2007)

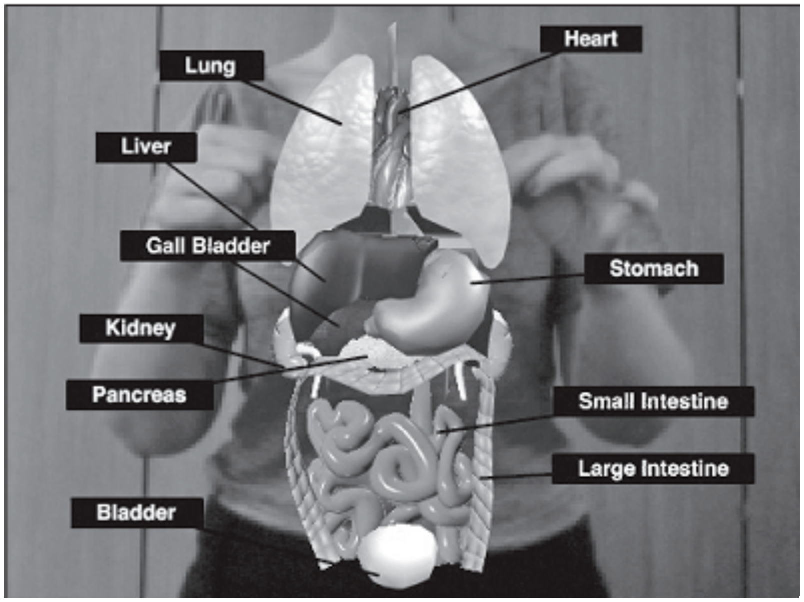


Figure 2 A model of human beings' internal organs with AR technology that can be used in Biology class (Retrieved from http://www.ssatrust.org.uk/). Image by courtesy of Te Schools Network.(Kangdon Lee)

However technology is not by itself a vehicle for learning even if information technology have been presented as a driver for educational reforms (Merrill, 2002; Salomon, 2002). To prevent AR being a gimmick with tremendous potential, it is important to have a clear understanding the new capabilities that technology offers in relation to its impact on learning (Garrison & Zehra, 2009; Salinas, 2008). A necessary first step is therefore to analysis the current research on AR application in healthcare education to identify the strengths and weaknesses.

There are few existing systematic reviews about AR, one (Al-Issa, Holger, & Hale, 12AD) is on AR applications in rehabilitation to improve physical outcomes; another (Rabbi, Ullah, & Khan, 2012) focused on AR tracking techniques. (Lee, 2012) published a literature review to describe AR applied in training and education and discussed its potential impact on the future of education. (Carmigniani & Furht, 2011) made an overview of AR technologies and their applications in different area. (Shuhaiber, 2004) discussed augmented reality in the field of surgery and its potential goals in education, surgeon training and patient treatment. (Thomas et al., 2010) provided a brief overview of augmented reality for e-health applications in the medical domain with a special focus on issues of user-centered development. (Ong, Shen, Zhang, & Nee, 2011) presented the applications of AR in assistive technology and rehabilitation engineering focusing on the methods and application aspects. None of the studies include in these reviews have focused on medical or healthcare education except for two. The first is (Berg & Treskunov, 2011) who reviewed the current state of mixed reality manikins for medical education. The second (S. M. B. I. Botden & Jakimowicz, 2009) analyzed AR application in laparoscopic surgery where they focused on training. They were helpful in understanding of AR from different perspectives but lacked the analysis of the learning and the teaching which is important for the appropriate instruction design in medical education with AR.

This review focused therefore on AR in healthcare education and investigated the strengths and weakness in the existing body of evidence.

2. Material and Methods

We conducted an integrative review as described by Whittemore and Knafl (2005). Integrative reviews are the broadest type of research review methods allowing for the inclusion of various research designs to more fully understand a phenomenon of concern. Our review included multi-disciplinary research publications reported until 2012 that were related to the construct of augmented reality in healthcare education.

2.1. Inclusion and exclusion criteria

In order to present a comprehensive overview of AR in relative healthcare education, we use the broad inclusion criteria. An article was included in review if it is a research paper *) on AR **) application in healthcare education ***) and was written in English. The criteria of inclusion and exclusion were further defined as follows and table 1:

Table 1 *the inclusion and exclusion criteria*

Criterion	Inclusion criteria	Exclusion criteria
Research	Clearly described of the goal or research question.	Neither goal Nor research question described
	A scientific study design.	Review papers were put in introduction
	The data collection and analysis methods were clearly described.	
	The result was clearly described.	
Focus of the Technology	Combination of real and virtual. Interactive in real-time Real or perceived registration in 3D	Virtual reality which use mixed reality as name
Content	Healthcare education	Education without medicine
	Health science education	Medicine without education
	Medical education	Veterinary medicine education

- Research paper: There is no widespread accepted set of criteria with which to assess the quality of study. And research paradigm is different among different academic community such as developer, educator and doctor. We have not restricted the methodology and the writing style but it should be base requested reported about clear description of the context, study aims, research question, study design, sampling, data collection and analysis, and findings. It would be excluded if it is not described the base information above mentioned.
- AR: augmented reality, which sometimes referred to as 'mixed reality', or 'blended reality', is a technology that allows live real-time direct or indirect real-world environment augmented/enhanced by computer-generated virtual imagery information(Carmigniani & Furht, 2011; Lee, 2012). It is different from Virtual Reality

which completely immerses a computer-generated virtual environment. We did not make a clear distinction between augmented reality and augmented virtuality (AV) where AR is closer to the real world and AV is closer to a pure virtual environment by (Milgram & Colquhoun, 1999). Studies focusing on enhancing the user's perception of and interaction with real world with virtual information were included. It would be excluded if it is only discussed virtual environment.

- Healthcare education: According the glossary of medical education terms from AMEE (Wojtczak, 2002), medical education is the process of teaching, learning and training of students with an on-going integration of knowledge, experience, skills, qualities, responsibility and values which qualify an individual to practice medicine. With the growing understanding of the conditions for learning within medical care and health care and the increasing focus on the "lifelong" nature of medical education, medical education has not always been spanned three sectors: undergraduate, postgraduate and the continuing professional development of established clinicians(Swanwick & Buckley, 2010).

2.2. Search strategy and inclusion procedure

EZ discussed with NZ and IM to get the agreement about the review protocol, Inclusion and exclusion criteria. Relevant computerized databases were searched for eligible studies: ERIC, CINAHL, Medline, Web of Science, PubMed, Springer -link. A search was set up for each database separately, with no date restrictions, and no methodological filter, language limited to in English. The searches were updated until November 2012. Word groups representing the key elements: 'augmented reality' and words whose meaning is similar such as 'mixed reality', 'blended reality'; 'education' and 'medic*' and 'health*' were combined in several ways. For example: augmented reality and medical education, augmented reality and medicine education, augmented reality and healthcare education, augmented reality and health care education, augmented reality and health science education and so on.

EZ independently searched for eligible studies in the six databases using different ways and identified each article applied the inclusion criteria. After confirmation that the title and abstract addressed augmented reality in medication education, the full text was downloaded and printed to re-read and analyze if the review criteria were met. EZ examined and marked the full texts to select the articles that met the inclusion criteria firstly. AH checked the excluded papers by EZ to make sure that we did not leave out which we should include. NZ checked the full text and discussed with EZ. IM were involved in the discussions and selection process when necessary. Each criterion was marked using different colors. The quality of the studies was then reviewed by all the co-authors for final inclusion.

2.3. Assessment of the relevance of research

Three main forms of research process according different aims are exploratory research, constructive research and empirical research. In medical research, empirical evidence is important to keep the effective. But in computer science application area, researchers often deal with algorithm, model, software or a framework and the most common is constructive research. Not only AR is a new technology and new application in different area and there are not accepted theories or laws for the practical application but also there is need for flexibility in approaching the problem. Most of the research on AR in healthcare education is exploratory.

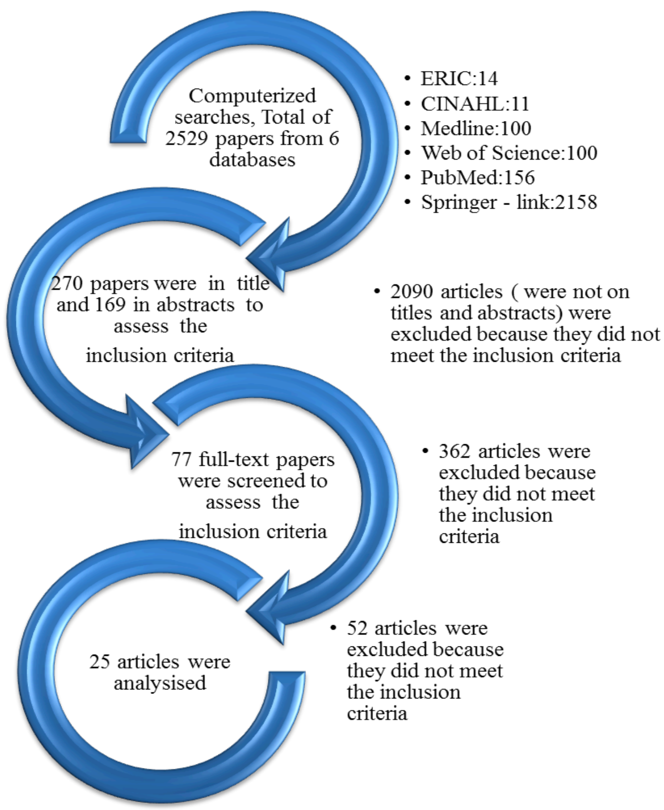
2.4. Data extraction and analysis

We abstracted relative information on research, technology and learning. The characteristics and the results of the studies that are included in the review were recorded with a standardized data-extraction form. Data were extracted independently and in tripartite for all variables. Thematic analysis was used to identify the prominent themes that could be described about current AR in healthcare education. Three aspects characteristics and eleven sub-item categories were described from research, technology and learning in Table 2 through thematic analysis. Content analysis was used as a means of synthesizing study to analysis all characters related to AR in healthcare education. A global view and the strength and weakness were obtained from the results of the studies among investigators. Figure4 displays the map of AR in healthcare education that gives us the clear understanding of learning paradigm and the capabilities of AR offered in current research. Also we used content analysis to describe the methodology of included papers (Table 3).

3. Results

3.1. Identification of relevant studies

Figure 3. Literature search and selection flow



We found 2529 papers on AR in medical education in the above-mentioned six databases. After screening the titles and abstracts, 270 citations in the title and 179 in abstract that included 'augmented reality', 'mixed reality' or 'blended reality' since we focused on the concept that we wanted to scrutinize and identify. In the further reading of the title and abstracts and getting rid of the repeating, 77 full-text papers were retrieved and reviewed in more detail. 25 articles for the data extraction that met out inclusion criteria were analyzed. *Figure 3* shows the selection process. Papers were mainly excluded because their research aim and context were not clearly described. Some articles (Bruellmann, Tjaden, Schwanecke, & Barth, 2012; Loreto, Dokkum, Gouaich, & Laffont, 2011; Pagador et al., 2011) which seemed to discuss medical education were excluded later because they only focused on medicine or treatment and not not on healthcare education. And vice versa, (Hsiao, 2012) discussed education of other discipline which will contribute to health of students.

3.2. Methodological quality of the identified studies

We chose to apply a broad inclusion criteria and no restriction with regard to the methodology since research on AR is still in an early innovative phase. Methodological quality was presented adapting the Medical Education Research Study Quality Instrument (MERSQI) (Reed et al., 2007). Quality (Table 2) was assessed purely for description not to exclude articles on these grounds.

Table 2 *Quality of included papers*

DOMAIN	ITEM		STUDIES NO. %
Study design*	Experiment	1 group posttest only	2
		1 group pretest and posttest	1
		2 group randomized	6
		2 group nonrandom	5
		3 group nonrandom	4
	Descriptive	Interviews	3
		Questionnaire	10
		Case	2
Type of data	Assessment by study participant		10
	Objective measurement		18
Data analysis	Date analysis appropriate for study design		22
	Descriptive analysis only		19
	Beyond descriptive analysis		3
Outcome	Satisfaction, attitudes, perceptions, opinions, general fact		10
	Knowledge, skill		16
	Experiences		2(one in aim but not in report)
	Health care outcome		0
	No report		3

*Percentage may not sum up to 100% because some used fixed study design

Table 3 *Description of 25 Comparative Studies Included in the integrative review of AR in medical education*

Study	Research (Quantitative)				AR Technology				Learning		
	Aim	Design	Participant*	Result	Display	Tracking	Input Devices	Develop tool	Theory	Strategy	Effect
(Rasimah Che, 2011)	Investigated user's perception and acceptance of MR	Development, A pilot test, 22-item structured survey	63 SBS (2nd to 4th year)	Willing to try. ITU MR is affected mostly by PU, moderately by PEOU and weakly by PE. PEOU has strong positive correlation with PU and influence on PE, moderately with PI	Monitor-based	Web camera two-dimensional fiducially mark	Web camera, keyboard	FLARToolkit 3D tools, Photoshop, Sound Forge	Situated learning	Demonstration Brief hands on Task-oriented	Not clearly because it is not be tested
(Yeo et al., 2011)	Determined if AR guidance systems can assist medical trainees in learning essential skill	Development, Randomized Experiment, 2 groups, Posttest-only	40 =26 MS+ 9 BES+ 5 R 1st year)	The Overlay group performed better with less tissue trauma than the Control group. The system helped not only to avoid the initial period of high errors and lengthy procedures, but also improved overall accuracy and efficiency.	External monitor, semi-reflective glass	Electromagnetic tracker, radiographic markers	Perk Station phantom control box, a sensor attached to a needle	3D Slicer XML	No	image and laser guidance compare with classical freehand method	Decrease the amount of practice required to become eligible for clinical procedures
(Luciano et al., 2011a)	evaluated the learning retention on a augmented reality and haptic technology workstation	Experiment One group Posttest-only	51 fellows and R	The reduced failure rate from 16.9% to 12.5% Furthermore, The performance accuracy showed a 15% mean score improvement and more than a 50% reduction in standard deviation from practice to test.	high-resolution stereoscopic display	An electromagnetic head-and-hand tracking system landmarks	the haptic stylus an electromagnetic sensor.	The Immersive-Touch system (the system name)	No	Practice guided by fluoroscopic images	Reduced failure rate and accuracy performance improvement indicated the positive learning
(Feifer, Delisle, & Anidjar, 2008)	examined the usefulness, reliability and applicability of the smoothness metric of the ProMIS hybrid simulator	Nonrandom Experiment Two groups, Test, Post-test	15R= 8 PGYs (1 to 3) +7 PGYs (4, 5)	Statistically significant differences in all MISTELS tasks were evident for all 6 sessions. The differentiating capabilities of the hybrid simulator were maintained even after additional teaching in the junior group.	Computer screen (?)	camera tracking systems marked electrical tape	camera, real surgical instruments on	The ProMIS (the system name)	No	unsupervised simulator practice	A valuable asset for preparatory training for live operative experience, allowing improved trainee assessment
(Ritter, Kindelan, Michael, Pimentel, & Bowyer, 2007)	Proving the ProMIS metrics could differentiate groups as well as standard FLS scoring with fewer personnel requirements	Nonrandom Experiment, Three group test–retest	60 =8 AS/ CR +44 MS 3rd year/I +8 R (PGYs 2–4))	The more experienced the more outperformed. Statistically significant differences between the groups across all trials. A strong relationship between the FLS scores and the ProMIS metrics was apparent for three groups.	Computer screen?	separate camera tracking systems marked	actual laparoscopic surgical instruments plastic body mold with a neoprene cover	FLS and the ProMIS (the AR name)	The manual skills of FLS	Demonstration Performed up to five consecutive trials of the task.	Validation potential of remote assessment and training. Also lend nicely to proficiency-based training curricula.

*: SBS: students in biomedical science. MS: Medical student. BES: Biomedical engineering students. R: residents. PGYs: postgraduate years. AS: Attending surgeons. CR: Chief residents. I: Interns.

Table 3 *Continued*

Study	Research (quantitative)				AR Technology				Learning		
	Aim	Design	Participant*	Result	Display	Tracking	Input Devices	Develop tool	Theory	Strategy	Effect
(Kotranza, Lind, & Lok, 2012)	enhancing of cognitive-psychomotor tasks within MREs with real-time visual feedback of learner task performance	Development, Nonrandom Experiment, Three group pre-test in I post-tests in II	69=41 MS + 3 I +15 PAS + 5 R+5 C in study I 13=8(from StudyI)+5 CS in study II	Novices receiving real-time feedback performed equivalently or better than more experienced practitioners. Skills improvement in the MRE transfers to the real-world task of CBE of human patients through repeated practice of CBE in the MRE	Notebook screen	the infrared webcam the infrared marker	Sensors IR marker infrared-seeing webcam physical breast model	unsupervised machine learning techniques, information-visualization	Expert-novice	In Study I: demonstrating, performed In Study II, performed	The efficacy of real-time feedback improving performance in complex real-world tasks
(Oostema, Abdel, & Gould, 2008)	Determine the computer-derived metrics for a hybrid simulator correlated with laparoscopic surgical skill.	Experiment, One group Performed recorded analysis	24 MS(3rd year)+19 R (PGYs 1–5) +3AS	Statistically significant correlation between experience and performance for all three metrics.	Computer	Not clearly see ProMIS	no clearly see ProMIS	ProMIS	No	Demonstration videos,Repeat the tasks until the metrics for three valid repetitions	Facilitating learning at a time convenient for trainees without the presence of instructors.
(Yudkowsky et al., 2012b)	studied the impact of simulator practice on simulated and live surgical performance	Development Pilot Testing, One Group Pre and post-tests survey questionnaire	16R (PGYs 1-4 and up)	Both simulation-based and live procedure outcome measures showed significant improvement after practice, demonstrating that skills obtained on the simulator could be transferred to the surgical setting	High-resolution high-pixel density stereoscopic display	a head-and-hand tracking system	haptic stylus CT scans	Computed tomographic scan images?	No	Random Presentation practice case one by one	Especially by novice residents, may accelerate learning and shorten the learning curve
(Nischelwitzer, Lenz, Searle, & Holzinger, 2007)	How to design and develop applications for educational purposes with the use of the ARToolkit	Development usability Test Experiment, two group, Pre and post - questionnaire	18 children between 7 and 13 years	Used the MIBB acquired more knowledge than just read the text and the audio guides. The interaction with the virtual organs seems to improve understanding the functionality of the alimentary canal.	HMD?	Webcam markers	The interaction control pad	ARToolKit	No	Interactive story	The possible potential of AR in the area of learning
(Jan, Noll, Behrends, & Albrecht, 2012)	Powered learning environment duo to the ubiquitous availability of mobile phones	Randomly Two group structured questionnaire	10MS 3rdyear	Above-average values for hedonic quality and being highly attractive for users. The AR group answered questions more correctly than the textbook group.	Mobile phone screen	Narker camera	Camera, navigation controls icon	xml	No	Self-learning; group learning	Easier to capture learners attention. Possibility for significantly improving the learning process.

*PAS: Physician assistant student. C: Clinicians. CS: clerkship students

Table 3 *Continued*

Study	Research (quantitative)				AR Technology				Learning		
	Aim	Design	Participant*	Result	Display	Tracking	Input Devices	Develop tool	Theory	Strategy	Effect
(Pretto, Manssour, Lopes, Silva, & Pinho, 2009)	Up-date the traditional training environment for LS by introducing image and sound resources into the training manikins	Development Pilot Study Validation Tests post-test interview questionnaire	13 final year MS for Validation Tests. 70 Medical Residency examination candidate	The facial expressions and the body injuries stimulate the trainees in the direction of a more autonomous evaluation of the patient, which is very important for emergency care.	Projector A mask placed on the manikin face. audio connectors	No tracking	Camera waistcoat audio-connectors speakers	Tailor-made software, ARToolkit, Expression Toolkit, C++	No	autonomous observation proper medical care	The implemented feature are significantly relevant for emergency care training
(S.Botden, Buzink, Schijven, Jakimowicz, 2007, 2008; S. Botden, Hingh, & Jakimowicz, 2009a, 2009b)	To evaluate the training system value and validate assessment method，the face validity ， the suturing module of the ProMIS AR	Nonrandom Experiment, Three group/ two group based on clinical experience Structured questionnaire	90=27I+25SR+7R+30Sur+1Spec 55=21SR+4R+29Sur+1Spec 24 18	The ProMIS is regarded as more realistic and having better haptic feedback and as being more useful for training surgical residents. It is a valid tool for objectively assessing laparoscopic suturing skills	Computer screen?	camera tracking systems Marked electrical tape	torso-shaped mannequin camera real surgical instruments on	the ProMIS (the AR name)	No	Demonstration Performed task	Useful for training surgical residents.
(LeBlanc et al., 2010; Leblanc, Delaney, Ellis, et al., 2010; Leblanc, Delaney, Neary, et al., 2010; Leblanc, Senagore, et al., 2010)	to compare laparoscopic colorectal skill acquisition among HAL and SL on an AR simulator and human cadaver	Randomized Experiment two group preformed recorded analysis	38=29 PS+9 JS (5 fellows and 4 R) 29 PS 34PS	Better performances with the hand-assisted approach. Technical skills scores and generic events score was considerably better on the simulator than on the cadaver. Overall satisfaction was better for the cadaver than simulator.	Computer screen?	cameras incorporated into the body of the simulator(?) for HAL A 0O laparoscope for SL (?)	real surgical instruments on	The ProMIS 2.5 (the AR name)	No	Demonstration simulator	the ability for novice surgeons to perform several complete operative procedures
(Sakellariou, Ward, Charissis, Chanock, & Anderson, 2009)	Depict meaningful information enhance the learning process in an augmented reality environmen	Development experiment, two group, pre and post -assessment open and Structured questionnaire	12 medical trainees	The traditional method group with a mean improvement in scores of 16%,whilst the VR method group improvement of 25%. Positively phrased statements regarding the educational approach scored very highly in the VR group .	CrystalEyes shutter glasses	tracked by the table -sensors	haptic glove 3D spatialised speakers		Activity-based learning	Not clearly	better understanding of the spatial interrelationships of the structural elements of the canal

*: PS: Practicing surgeons. JS: Junior surgeons. SR: Surgical residents. Sur: Surgeon. Spec: Specialist

Table 3 *Continued*

Study	Research (qualitative)				AR Technology				Learning		
	Aim	Design	Participant	Result	Display	Tracking	Input Devices	Develop tool	Theory	Strategy	Effect
(Nilsson & Johansson, 2008)	To see whether AR technology socially accepted by the staff at the hospital.	Case study interviewed, open questionnaire, videotaped observation	8=4 Exp + 4 Nov) in case 1. 12 professional (OR) nurses and surgeons in case 2	The overall result from both cases studies shows a system that the participants like rather than dislike. The participants would like to use AR instructions in their future professional life.	HMD with camera in case 1. HMD and earphones and micro-phone	marker tracking, camera	num pad with buttons in case 1. voice input in case 2	ARTool Kit ARTool Kit Plus ARTag integrate dset of software tools	No	Demonstration Performed task	The users are positive towards AR systems as a technology for instructions in terms of usefulness and social acceptance
(Lamounier , Bucioli, Cardoso, Andrade, & Soares, 2010)	To provide a friendly and intuitive interface based on AR	System architecture Development Test the system	2 volunteers	More natural and intuitive interface different input types: the ECG image capture and the sensor, text input and load from a file confirmed the suitability of AR for health applications	Computer screen	camera monochr omatic marker	Sensor, Camera Keyboard	Simulatio n software. Irfraview Chromak ey	No	Not clearly	It is useful and interesting tool that can help Medicine student
(Davis et al., 2002; Rolland, 2003)	Propose an interactive tool for training involve programming of instructor feedback	Development Preliminary tests local and remote tests observation	no	The average delays are the same for the local and remote tests prove that the application can be run across distributed platforms.	HMPD	Polaris hybrid optical tracker,	Not clearly	METI. VESS Visible Human data sets. 3D CAD-model C/C++.	No	Not clearly	The system will allow paramedics to practice their skills and provide them with the visual feedback they could not otherwise obtain

Study	Research (quantitative, qualitative)				AR Technology				Learning		
	Aim	Design	Participant	Result	Display	Tracking	Input Devices	Develop tool	Theory	Strategy	Effect
(Rosenbau m, Klopfer, & Perry, 2007)	Do students understand the dynamic nature underlying the game and perceive it as an authentic experience?	Phenomenology Experiment, 3 group pre-&post-survey, Interviews Video-taped and transcribed.	21 high school students (15 girls and 6 boys),	Students perceive the game as authentic in several ways. Some students did understand the game as a complex dynamic system	PDA Screen	Wi-Fi signal strength	PDA Walkie-talkie	Outbreak @ the Institute is their AR name	On Location Learning	Presentation, Collaboration inquiryRole play	Incorporating the affordances of AR games and the dynamic models of participatory simulations make possible new kinds of authentic science inquiry experiences
(Karthikeya n, Mani, Balasubram aniyan, & Selvam, 2012a)	use AR along with serious games improve the medical training process and user experience	Experiment Questionnaire	Not clearly	The use of augmented reality in serious games will improve the learning process and also allows the user to interact with the game environment freely.	Not clearly	EGM and GSR sensors	Not clearly	ARTool Kit Humanist serious games	No	game play	The use of augmented reality in serious games will improve the learning process

3.3. Use of augmented reality applications in healthcare education

The earliest study on AR in healthcare education was published in 2002 but publications in the field take on starting from 2008 (See table 3). There is a high variability in the research aims and also the role of AR for healthcare education (table 4). 12 studies focused on evidence that AR can improve learning. 7 studies aimed at developing AR system for healthcare learning. 2 studies investigated the user's acceptance of AR as learning technology. 6 studies tested AR applications. The main use of AR for learning is to provide feedback. 8 studies used AR as a mean to provide feedback to students. 2 studies used AR as an innovative interface and 2 studies used it for simulator practice. The other studies tried AR as navigation, regenerative concept, remote assessment and train, meaningful information tool. One used it to reduce resources. One group used it offer immerse in the scenario and one try to give participatory reality. The research result showed that learner can accept AR as learning technology and can improve learning effect from acquisition skill and knowledge, understanding the spatial interrelationships and medical concepts, enhancing learning retention and cognitive-psychomotor, providing time convenient and shorten learning curve, giving subjective attractiveness and authentic simulated experiences (see table 3 and 4).

Table 4 *The Characteristics of AR in medical education*

Subject	Research Aim	The Role of AR	Learner	Platform
Surgery • Percutaneous facet injection (1) • Thoracic pedicle screw placement (1) • Laparoscopic (11) • Endotracheal Intubation /airway anatomy (2) • Ventriculostomy (1) Other areas of health sciences • Forensic medicine (1) • Inguinal canal anatomy (1) • Diathermy (1) • Alimentary canal physiology and anatomy (1) • Disease outbreak (1) • Tissue engineering (1) • Clinical breast (1) • Cardiologic (1) Clinical Life Support(1)	Investigated user acceptance (2) Develop system for learning (7) • Low-cost (1) • Simulation (4) • Integration (2) Test system • Usefulness (3) • Reliability and applicability(1) • Validity (4) • Value (1) Improve learning • Skill acquisition (6) • Learning retention (1) • Cognitive-psychomotor (1) • Time convenient (1) • Shorten learning curve (1) • Acquired more knowledge (3) • Subjective attractiveness (1) • Authentic simulated experiences.(2)	Explore (1) Guidance (1) Feedback (14) Remote assessment and training (1) Simulation practice (2) Innovative interface (2) Immerse in the scenario(1) Meaningful information(1) Reduce resources needed(1) Participatory Reality (1)	Undergraduate medical students (113) Clerkships/ Interns (135) Residents/ postgraduate (185) Healthcare workers(113) • Nurse • Surgeon • Clinics • Others Misc learners (41) • High school (21) • Children(18) • Volunteers(2)	Computer (7) Laptop (11) Tablet/PDA (Mobile Phon (1) eBook (1)

*The number is the total of unique participants for all the included papers. We used their largest number for two groups (S.Botden et al & Leblanc et al) who published 4 papers.
**The number is the included papers which use this computer system. 3 Papers did not describe computer system(Karthikeyan, Mani, Balasubramaniyan, & Selvam, 2012b; Sakellariou et al., 2009; Yudkowsky et al., 2012a)

Three papers did not mention which computing system they used to process the virtual information. Most of included papers (50%) employed laptop as a mobile computing system. Few used other lighter mobile configuration as follow: 1 smart phone, 1 tablet, 1 PDA and 1 book. 7 papers used computer as stationary systems.

68% included papers used camera and marker as tracking device. 2 papers used electromagnetic tracker but different marker. One is a radiographic marker and another landmarks. 2 papers used sensors. Other tracing systems such as hybrid optical tracker and Wi-Fi signal each could be found one included paper. A paper said using a head-and-hand tracking system but we cannot find the detail technology (Yudkowsky et al., 2012a). One did not use tracking devices because they projected the virtual picture to the manikin.

3.4. The strengths and weaknesses in the current research about AR learning system for healthcare education

3.4.1. The strengths

AR was applied in different healthcare areas and aimed at all level of learners

AR was applied in different subjects such as: percutaneous facet injection, thoracic pedicle screw placement, Laparoscopic, administering local anesthesia, endotracheal intubation, ventriculostomy, forensic medicine, inguinal canal anatomy, diathermy, tissue engineering, alimentary canal physiology and anatomy, disease outbreak, Clinical Breast, Cardiologic, Clinical Life Support which are relative healthcare education (see Figure 3), 64% included papers are in surgery especially for Laparoscopic which are 44% (11/25). And two groups(S. Botden et al., 2007, 2008, 2009a, 2009b; LeBlanc et al., 2010; Leblanc, Delaney, Ellis, et al., 2010; Leblanc, Delaney, Neary, et al., 2010; Leblanc, Senagore, et al., 2010) gave the most publications of laparoscopic. Any other healthcare subject area just has one paper to research.

Other than two studies did not mention participations. 713 people who are medical staff, medical students, high school students and children were participated in 23 studies (see table 2 and figure 2). They use AR to learning different healthcare skill and knowledge. Most of participants are or will be healthcare staff. The children and high school students who learn about health knowledge by AR may not be going to do relative healthcare working in their future.

AR was proved useful for improving healthcare learning from different educational objectives

Although the research aim of included papers are different. 96% papers claimed that AR is useful for healthcare learning from different aspect such as: decreased the amount of practice, reduced failure rate and accuracy performance improvement, accelerate learning and shorten the learning curve, Easier to capture learners attention, better understanding of the spatial interrelationships, provided new kinds of authentic science inquiry experiences and improved trainee assessment.

Broad focus of research - from user acceptance, system development and test to the study of learning effects

Every paper has its own research aim and focus. They give us a more complete perspective when we put them together (figure 2). Two papers investigated the user acceptance of AR and they claimed that participants would like to use AR instructions in their future professional life especial for the perceived usefulness of AR. 6 papers focus on developing AR system and two of them were tested the usefulness of the system. In addition to one of the six studies, other two groups focus on evaluation the validity of AR system. One paper described the usefulness, reliability and applicability of the system. One tested the system value.14/25 papers presented AR application for different learning aim.

3.4.2. The weaknesses:

Lack of learning theories to guide the instructional design

80% included papers did not clearly describe which kind of learning theory was used to guide design or application AR for healthcare education. One claimed that they used activity-based learning but did not tell us how they used it, moreover, the learning strategies is not clearly described in the paper. Two groups used standard skill such as the manual skills of FLS or expert mode to guide design AR system. The participants performed the standard steps of the task. One group that used situated learning allowed the participants explore and navigate with AR environments but did not show the learning effect. Only one group used on location learning theory and the learning strategy of collaboration inquiry and role play, the result indicated that incorporating the affordances of AR games and the dynamic models of participatory simulations make possible new kinds of authentic science inquiry experiences.

Most of learning strategies were the traditional 'see one, do one and teach one'

64% included papers, whether AR were used as guidance system or as feedback tool, showed that they still use the traditional way of teaching practical skills in medical education. 3 papers which are 12% included did not describe how the participating used AR to learn. One wrote that students can explore and navigate with AR environments but the time only was half an hour and they did not show a learning effect.

A study investigated AR in teaching using different forms such as group setting, self-learning or revision of cases. A research group used interactive story and another group used game play to attract students. One group used collaboration inquiry and role-play strategies.

Most of AR applications were still in a prototype stage of development.

56% of the papers presented AR prototype without further studying its impact. 5 groups studied the ProMIS AR simulator, which was used to improve laparoscopic colorectal skills by colorectal surgeons in training. The 5 groups contributed with 11 papers. The usefulness, reliability and applicability of ProMIS AR simulator system were examined, and evaluated also the systems' value and validity. ProMIS AR was also compared to other system.

4. Discussion

We included 25 research papers focusing on AR application on healthcare education. 20 of which were based on quantitative research methods, 3 on qualitative research methods and 2 on mixed research methods. In these studies, AR was applied on 15 healthcare related subjects. Most of studies use their own AR system and 5 groups use the same system.

Except one group did mentioned the learning effect, most of them said AR is useful for healthcare education. AR is not only useful for healthcare learner understanding the spatial interrelationships and concepts, acquiring the skill and knowledge, strengthening cognitive-psychomotor, shortening learning curve and prolonging learning retention, but also is subjective attractiveness for student because it provided them the authentic simulated experiences. Moreover, it is convenient on time.

The most cases used AR for learning as feedback or navigation system. But still few used it offer immerse in the scenario, participatory reality or regenerative concept. Some use AR as innovative interface or meaningful information tool. The others tried AR for remote assessment and training or simulator practice. One used it to reduce resources.

4.1. Comparison with existing literature

Two literatures relative healthcare education focused on several cases introduction. (Berg & Treskunov, 2011) introduced human manikins with augmented sensory input for medical education.(S. Botden & Jakimowicz, 2009) compared three AR systems that allow the trainee to use the same instruments currently used in the operating room for laparoscopic surgery. (Al-Issa et al., 12AD) used systematic review to investigate the effectiveness physical outcomes of AR applications in rehabilitation. It is not included rehabilitation training and also showed that the research in AR applications in rehabilitation is still in its infancy. (Rabbi et al., 2012) tried systematic review Augmented Reality Tracking Techniques but did not show the result. (Carmigniani & Furht, 2011) focused on analysis the technical specifications of different AR and pointed out the advantage and disadvantage. They also discussed the applications including medicine and education. This review searched different databases to find out the characters of AR in healthcare education and distinguish the strength and weakness on current research. It expanded included study with the subject's related healthcare education. There are more AR application based mobile computing systems especially for laptop. It is different with (Carmigniani & Furht, 2011) found that medical AR application systems are fixed in door. Light mobile AR was once predicted to be considered feasible to develop real-time AR applications locally processed in the near future that are still few in our finding. We are not only to describe the research outcome and learning effect of included paper, but also to check which kind of learning theory was used and how they used it.

4.2. Study strengths and limitations

To our knowledge, this is the first systematic review that specifically addresses AR application in healthcare relative education. How AR was applied in healthcare education encompassing a broad range of learners, learning strategy, outcomes and study designs. Content analysis and thematic analysis are useful to provide comprehensive understanding about AR application in healthcare education.

This review try to comprehensive describe AR application in healthcare relative education with no research methodology filter. It could be possibility that some studies were missed when the key words did not appear on the tile or abstract. Language limited English because most of papers were published in English and we can reach a consensus about the included and analysis standard among authors who come from different country. It is useful to minimize bias but possibility excluded some important papers. Some interesting application could be missed because they did not publish research paper.

5. Conclusions

AR is at its early stage of application in healthcare education but it has enormous potential promoting healthcare learning based on the review of the pre-study. It is important to clarify how to use AR most effectively and cost-efficiently. (Carmigniani & Furht, 2011) divided AR systems which allow the user for movement or not into five categories: fixed indoor or outdoor systems, mobile indoor or outdoor systems, and mobile indoor and outdoor systems. Each system, which uses different type of tracking system, display and interface, has their own advantage and disadvantage. Deciding which type of system to be built should consider the learning aims, the user acceptance and cost-efficiency. Although each study presented a clear research aim, Few suggestions were given for choosing AR model which is better for healthcare education. Moreover, there is not enough evidence for an informed design of suitable learning activities with AR system where knowledge and skill could be integrated into the learner's world. Thus, further research in this area should be taken to clarify the appropriate AR model, instructional designs and how to effectively use AR for healthcare education.

6. Acknowledgements

This study was performed using intramural grants.

7. References

Al-Issa, H., Holger, R., & Hale, L. (12AD). Augmented reality applications in rehabilitation to improve physical outcomes.pdf. *Physical Therapy Reviews*, *12*, 16–28. doi:10.1179/1743288X11Y.0000000051

Bajura, M., Fuchs, H., & Ohbuchi, R. (1992). Merging Virtual Objects with the Real World : Seeing Ultrasound Imagery within the Patient. *ACM SIGGRAPH Computer Graphics*, *26*(2), 203–210. doi:10.1145/133994.134061

Berg, B., & Treskunov, A. (Eds.). (2011). Mixed reality Manikins for Medical Education. In *Handbook of Augmented reality* (pp. 943–956). Springer Science+Business Media, LLC. Retrieved from http://ugcs.caltech.edu/~andrei/PDF/Augmented_Reality_Handbook__manikins.pdf

Botden, S., Buzink, S., Schijven, M., & Jakimowicz, J. (2007). Augmented versus virtual reality laparoscopic simulation: what is the difference? A comparison of the ProMIS augmented reality laparoscopic simulator versus LapSim virtual reality laparoscopic simulator. *World journal of surgery*, *31*(4), 764–72. doi:10.1007/s00268-006-0724-y

Botden, S., Buzink, S., Schijven, M., & Jakimowicz, J. (2008). ProMIS augmented reality training of laparoscopic procedures face validity. *Simulation in healthcare : journal of the Society for Simulation in Healthcare*, *3*(2), 97–102. doi:10.1097/SIH.0b013e3181659e91

Botden, S., Hingh, I., & Jakimowicz, J. (2009a). Meaningful assessment method for laparoscopic suturing training in augmented reality. *Surgical endoscopy*, *23*(10), 2221–8. doi:10.1007/s00464-008-0276-3

Botden, S., Hingh, I., & Jakimowicz, J. (2009b, September). Suturing training in Augmented Reality: gaining proficiency in suturing skills faster. *Surgical endoscopy*. doi:10.1007/s00464-008-0240-2

Botden, S. M. B. I., & Jakimowicz, J. J. (2009). What is going on in augmented reality simulation in laparoscopic surgery? *Surgical endoscopy*, *23*(8), 1693–700. doi:10.1007/s00464-008-0144-1

Bruellmann, D. D., Tjaden, H., Schwanecke, U., & Barth, P. (2012). An optimized video system for augmented reality in endodontics: a feasibility study. *Clinical oral investigations*. doi:10.1007/s00784-012-0718-0

Carmigniani, J., & Furht, B. (2011). Augmented Reality: An Overview. In B. Furht (Ed.), *Handbook of Augmented Reality* (Vol. Springer S, pp. 3–46). Springer New York. doi:10.1145/1103900.1103926

Chris, C. (2010). How Augmented Reality Helps Doctors Save Lives – ReadWrite. Retrieved March 15, 2013, from http://readwrite.com/2010/06/02/how_augmented_reality_helps_doctors_save_lives

Davis, L., Ha, Y., Frolicht, S., Martint, G., Meyer, C., Norfleet, J., … Rolland, J. P. (2002). Augmented Realityand Trainingfor AirwayManagement Procedures. In J. D. Westwood (Ed.), *Medicine Meets Virtual Reality 02/10* (IOS Press., pp. 121–126).

De Paolis, L., Ricciardi, F., Dragoni, A. F., Aloisio, G., & Paolis, L. T. De. (2011). An Augmented Reality Application for the Radio Frequency Ablation of the Liver Tumors. In B. Murgante, O. Gervasi, A. Iglesias, D. Taniar, & B. Apduhan (Eds.), *Computational Science and Its Applications ICCSA 2011* (Vol. 6785, pp. 572–581). Springer Berlin / Heidelberg. Retrieved from http://dx.doi.org/10.1007/978-3-642-21898-9_47

Feifer, A., Delisle, J., & Anidjar, M. (2008). Hybrid augmented reality simulator: preliminary construct validation of laparoscopic smoothness in a urology residency program. *The Journal of urology*, *180*(4), 1455–9. doi:10.1016/j.juro.2008.06.042

Frenk J, Chen L, Bhutta ZA, et al. (2010). *HEALTH PROFESSIONALS FOR A NEW : Transforming education to strengthen health systems in an interdependent world. Lancet 2010* (pp. 1–116).

Garrison, D. R., & Zehra, A. (2009). Role of instructional technology in the transformation of higher education.pdf. *Comput High Educ*, *21*(Springer Science+Business Media, LLC 2009), 19–30.

Hanson, K. M. (2011). The Utilization of Mixed-Reality Technologies to Teach Techniques for Administering Local Anesthesia.

Hsiao, K.-F. (2012). Using augmented reality for students health - case of combining educational learning with standard fitness. *Multimedia Tools and Applications*. doi:10.1007/s11042-011-0985-9

Jan, V. U., Noll, C., Behrends, M., & Albrecht, U.-V. (2012). mARble - Augmented Reality in Medical Education. *Biomedizinische Technik. Biomedical engineering*, *57*, 67–70. doi:10.1515/bmt-2012-4252

Johnson, L., Smith, R., Willis, H., Levine, A., & Haywood, K. (2011). *The 2011 Horizon Report*. (New Media Consortium Educause Association, Ed.)*Media* (Vol. 2010, p. 36). The New Media Consortium. Retrieved from http://wp.nmc.org/horizon2011/

Karthikeyan, A., Mani, P., Balasubramaniyan, S., & Selvam, P. (2012a). Use of Augmented Reality in Serious Game for Training Medical Personnel. In N. Meghanathan, N. Chaki, & D. Nagamalai (Eds.), *Advances in Computer Science and Information Technology. Computer Science and Engineering* (Vol. 85, pp. 222–230). Berlin, Heidelberg: Springer Berlin Heidelberg. doi:10.1007/978-3-642-27308-7

Karthikeyan, A., Mani, P., Balasubramaniyan, S., & Selvam, P. (2012b). use of augmented reality in serious game for training medical personnel.pdf. In M. Meghanathan (Ed.), *Computer Sciences, Social Informatics and Telecommunications Engineering* (pp. 222–230).

Klopfer, E., & Squire, K. (2007). Environmental Detectives—the development of an augmented reality platform for environmental simulations. *Educational Technology Research and Development*, *56*(2), 203–228. doi:10.1007/s11423-007-9037-6

Kotranza, A., Lind, D. S., & Lok, B. (2012). Real-time evaluation and visualization of learner performance in a mixed-reality environment for clinical breast examination. *IEEE transactions on visualization and computer graphics*, *18*(7), 1101–14. doi:10.1109/TVCG.2011.132

Lamounier, E., Bucioli, A., Cardoso, A., Andrade, A., & Soares, A. (2010). On the use of Augmented Reality techniques in learning and interpretation of cardiologic data. In *Engineering in Medicine and Biology Society EMBC 2010 Annual International Conference of the IEEE* (Vol. 2010, pp. 610–613). IEEE. doi:10.1109/IEMBS.2010.5628019

LeBlanc, F., Champagne, B. J., Augestad, K. M., Neary, P. C., Senagore, A. J., Ellis, C. N., & Delaney, C. P. (2010). A comparison of human cadaver and augmented reality simulator models for straight laparoscopic colorectal skills acquisition training. *Journal of the American College of Surgeons*, *211*(2), 250–255. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/20670864

Leblanc, F., Delaney, C., Ellis, C., Neary, P., Champagne, B., & Senagore, A. (2010). Hand-assisted versus straight laparoscopic sigmoid colectomy on a training simulator: what is the difference? A stepwise comparison of hand-assisted versus straight laparoscopic sigmoid colectomy performance on an augmented reality simulator. *World journal of surgery*, *34*(12), 2909–14. doi:10.1007/s00268-010-0765-0

Leblanc, F., Delaney, C., Neary, P., Rose, J., Augestad, K., Senagore, A., … Champagne, B. (2010). Assessment of comparative skills between hand-assisted and straight laparoscopic colorectal training on an augmented reality simulator. *Diseases of the colon and rectum*, *53*(9), 1323–7. doi:10.1007/DCR.0b013e3181e263f1

Leblanc, F., Senagore, A., Ellis, C., Champagne, B., Augestad, K., Neary, P., & Delaney, C. (2010). Hand-assisted laparoscopic sigmoid colectomy skills acquisition: augmented reality simulator versus human cadaver training models. *Journal of surgical education*, *67*(4), 200–4. doi:10.1016/j.jsurg.2010.06.004

Lee, B. K. (2012). Augmented Reality in Education and Training, (April), 13–21.

Loreto, I. Di, Dokkum, L. Van, Gouaich, A., & Laffont, I. (2011). Mixed Reality as a Means to Strengthen Post-stroke Rehabilitation. In R. Shumaker (Ed.), *Virtual and Mixed Reality, Part II* (pp. 11–19). © Springer-Verlag Berlin Heidelberg.

Luciano, C. J., Banerjee, P. P., Bellotte, B., Oh, G. M., Lemole, M., Charbel, F. T., & Roitberg, B. (2011a). Learning retention of thoracic pedicle screw placement using a high-resolution augmented reality simulator with haptic feedback. *Neurosurgery*, *69*(1 Suppl Operative), ons14–9; discussion ons19. doi:10.1227/NEU.0b013e31821954ed

Luciano, C. J., Banerjee, P. P., Bellotte, B., Oh, G. M., Lemole, M., Charbel, F. T., & Roitberg, B. (2011b). Learning retention of thoracic pedicle screw placement using a high-resolution augmented reality simulator with haptic feedback. *Neurosurgery*, *69*(1 Suppl Operative), ons14–9; discussion ons19. doi:10.1227/NEU.0b013e31821954ed

Lucio T. De Paolis, Pulimeno, M., & Aloisio, G. (2008). An Augmented Reality Application for Minimally Invasive Surgery. In *14th Nordic-Baltic Conference on Biomedical Engineering and Medical Physics IFMBE Proceedings* (pp. 489–492).

Merrill, M. D. (2002). Effective Use of Instructional Technology Requires Educational Reform. *Educational Technology*, *42*(ISSN/0013/1962), 13/16. Retrieved from http://kib.summon.serialssolutions.com/en/document/show?id=FETCH-eric_primary_EJ6649361&s.dym=false&s.q=Author%3A%22Merrill%2C+M.+David%22

Milgram, P., & Colquhoun, H. (1999). A Taxonomy of Real and Virtual World Display Integration. In Y. Ohta & H. Tamura (Eds.), *Environments* (pp. 1–26). Springer. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.32.6230

Nilsson, S., & Johansson, B. (2008). Acceptance of augmented reality instructions in a real work setting. *Proceeding of the twenty-sixth annual CHI conference extended abstracts on Human factors in computing systems - CHI '08*, 2025. doi:10.1145/1358628.1358633

Nischelwitzer, A., Lenz, F., Searle, G., & Holzinger, A. (2007). Some Aspects of the Development of Low-Cost Augmented Reality Learning Environments as Examples for Future Interfaces in Technology Enhanced Learning. In C. Stephanidis (Ed.), *Universal Access in HCI, Part III,* (pp. 728–737). Springer-Verlag Berlin Heidelberg.

Ong, S. K., Shen, Y., Zhang, J., & Nee, A. Y. (2011). Augmented Reality in Assistive Technology and Rehabilitation Engineering. In B. Furht (Ed.), *Handbook of Augmented Reality* (pp. 603–630). New York, NY: Springer New York. doi:10.1007/978-1-4614-0064-6

Oostema, J. A., Abdel, M. P., & Gould, J. C. (2008). Time-efficient laparoscopic skills assessment using an augmented-reality simulator. *Surgical Endoscopy*, *22*(12), 2621–4. doi:10.1007/s00464-008-9844-9

Pagador, J. B., Sánchez, L. F., Sánchez, J. a, Bustos, P., Moreno, J., & Sánchez-Margallo, F. M. (2011). Augmented reality haptic (ARH): an approach of electromagnetic tracking in minimally invasive surgery. *International journal of computer assisted radiology and surgery*, *6*(2), 257–63. doi:10.1007/s11548-010-0501-0

Pandya, A., Siadat, M.-R., & Auner, G. (2005). Design, implementation and accuracy of a prototype for medical augmented reality. *Computer aided surgery official journal of the International Society for Computer Aided Surgery*, *10*(1), 23–35. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/16199379

Pretto, F., Manssour, I. H., Lopes, M. H. I., Silva, E. R. da, & Pinho, M. S. (2009). Augmented reality environment for life support training. In *SAC '09 Proceedings of the 2009 ACM symposium on Applied Computing* (pp. 836–841).

Rabbi, I., Ullah, S., & Khan, S. U. (2012). Augmented Reality Tracking Techniques_ a systematic literature.pdf. *IOSR Journal of Computer Engineering (IOSRJCE)*, *2*(2), 23–29.

Rasimah Che. (2011). Evaluation of user acceptance of mixed reality technology. *Australasian Journal of Educational Technology*, *27*(8), 1369–1387. Retrieved from http://www.ascilite.org.au/ajet/ajet27/rasimah.html

Reed, D. A., Cook, D. A., Beckman, T. J., Levine, R. B., Kern, D. E., & Wright, S. M. (2007). Association between funding and quality of published medical education research. *JAMA :*

the journal of the American Medical Association, *298*(9), 1002–9. doi:10.1001/jama.298.9.1002

Ritter, E. M., Kindelan, T. W., Michael, C., Pimentel, E. a, & Bowyer, M. W. (2007). Concurrent validity of augmented reality metrics applied to the fundamentals of laparoscopic surgery (FLS). *Surgical endoscopy*, *21*(8), 1441–5. doi:10.1007/s00464-007-9261-5

Rolland, J. (2003). DEVELOPMENT OF A TRAINING TOOL FOR ENDOTRACHEAL INTUBATION : In J. D. Westwood (Ed.), *Medicine Meets Virtual Reality II* (IOS Press., pp. 288–294).

Rosenbaum, E., Klopfer, E., & Perry, J. (2007). On Location Learning: Authentic Applied Science with Networked Augmented Realities. *Journal of Science Education and Technology*, *16*(1), 31–45. doi:10.1007/s10956-006-9036-0

Sakellariou, S., Ward, B. M., Charissis, V., Chanock, D., & Anderson, P. (2009). Design and Implementation of Augmented Reality Environment for Complex Anatomy Training : Inguinal Canal Case Study, 605–614.

Salinas, M. F. (2008). From Dewey to Gates: A model to integrate psychoeducational principles in the selection and use of instructional technology. *Computers & Education*, *50*(3), 652–660. doi:10.1016/j.compedu.2006.08.002

Salomon, G. (2002). Technology and Pedagogy: Why Don't We See the Promised Revolution? *Educational Technology*, *42*(0013-1962), 71 – 75. Retrieved from http://kib.summon.serialssolutions.com/en/document/show?id=FETCHMERGED-eric_primary_EJ6649221&s.q=Technology++and++pedagogy%3A+Why++don%E2%80%99t++we++see++the++promised++revolution%3F+Educational+Technology

Shuhaiber, J. H. (2004). Augmented Reality in Surgery. *ARCH SURG*, *139*, 170–174.

Sielhorst, T., Obst, T., Burgkart, R., Riener, R., & Navab, N. (2004). An Augmented Reality Delivery Simulator for Medical Training. *Nature Medicine*, *7*(6), 11–20. doi:10.1007/s11517-007-0231-9

Swanwick, T., & Buckley, G. (2010). *Understanding Medical Education Evidence, Theory and Practice*. (T. Swanwick, Ed.) (pp. xv–xvii). London: WILEY-BLACKWELL. Retrieved from http://www.google.se/books?id=3QvtYis7nIMC&printsec=frontcover#v=onepage&q&f=false

Thomas, R. G., John, N. W., & Delieu, J. M. (2010). Augmented reality for anatomical education. *Journal of Visual Communication in Medicine*, *33*(1), 6–15. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/20297908

Whittemore, R. and Knafl, K. (2005), "The integrative review: updated methodology.", Journal of advanced nursing, Vol. 52 No. 5, pp. 546-53

Wojtczak, A. (2002). Glossary of medical education terms: part 4. *Medical teacher*, *24*(5), 567–8. doi:10.1080/0142159021000012667

Yeo, C. T., Ungi, T., U-Thainual, P., Lasso, A., McGraw, R. C., & Fichtinger, G. (2011). The effect of augmented reality training on percutaneous needle placement in spinal facet joint injections. *IEEE transactions on bio-medical engineering*, *58*(7), 2031–7. doi:10.1109/TBME.2011.2132131

Yudkowsky, R., Luciano, C., Banerjee, P., Schwartz, A., Alaraj, A., Lemole, G. M., … Frim, D. (2012a). Practice on an Augmented Reality/Haptic Simulator and Library of Virtual Brains Improves Residents' Ability to Perform a Ventriculostomy. *Simulation in healthcare : journal of the Society for Simulation in Healthcare*, *8*(1), 25–31. doi:10.1097/SIH.0b013e3182662c69

Yudkowsky, R., Luciano, C., Banerjee, P., Schwartz, A., Alaraj, A., Lemole, G. M., … Frim, D. (2012b). Practice on an Augmented Reality/Haptic Simulator and Library of Virtual Brains Improves Residents' Ability to Perform a Ventriculostomy. *Simulation in healthcare : journal of the Society for Simulation in Healthcare*, *00*(00), 1–7. doi:10.1097/SIH.0b013e3182662c69

Zhou, F., Duh, H. B., & Billinghurst, M. (2008). Trends in augmented reality tracking, interaction and display: A review of ten years of ISMAR. (M. A. Livingston, O. Bimber, & H. Saito, Eds.)*2008 7th IEEEACM International Symposium on Mixed and Augmented Reality*, *2*(4), 193–202. doi:10.1109/ISMAR.2008.4637362