Augmented reality projections as a tool to enrich simulations in health care education: Combining AR projector technology with manikins

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Abstract. The advancement of augmented reality in recent years has increased the interest and potential of using the technology in various fields. In health care education augmented reality is becoming a popular tool, together with manikins, to enhance realism of patient interaction for students in a learning environment. The purpose of this research was to study an augmented reality projector and its ability to add an extra layer of realism to a manikin in a simulation setting. A focus was given to the results of the projections, the usability, the performance and the limitations of the technology in simulation, and how it compared to similar setups that were not specifically designed for augmented reality. Two scenarios were chosen to test the projector. The first scenario was to add a facial expression on the manikin to simulate pain, and the second scenario was to add blood flow to a surgical wound. The results showed that the projector gave the wanted effect in both scenarios, it was easy to use and flexible, and the performance was adequate for the use in this study. Some limitations were also discovered giving rise to possible future work. They included colour change and disturbances in the projections, and finding and fitting appropriate resources.

Keywords: Augmented Reality · Manikin · Projection · Health Care Education.

1 Introduction

Augmented Reality (AR) is a concept that more and more people are becoming familiar with. Azuma [2] described AR as: technology that adds additional information to the real world instead of replacing it, so that virtual and real objects coexist in the same space. A commonly accepted definition of AR is any system that has the following three characteristics: combines the real and virtual world, is interactive in real time, and is registered in 3D [29]. AR can be implemented with the help of different technologies, with the most common being head-mounted displays (e.g. glasses), handheld devices (e.g. smartphones and pads), and projector-based systems (e.g. projectors and cameras).

AR technology has been around for decades and has been applied in a variety of educational settings, including health care education. With the advancement of the technology and the increasing number of applications, the interest in AR in health care training and its potential have grown [27]. AR is said to have a number of benefits when applied in health care education. Some of these benefits are listed by Zhu et al. [31]:

- Reducing the amount of practice needed.
- Reducing failure rate.
- Improving performance accuracy.
- Accelerating learning speed and shortening learning curves.
- Capturing learners' attention.

Within health care education the use of AR together with manikins is becoming a popular tool to make patient simulations more realistic for students [25, 11, 30]. Research has been conducted on various kind of AR technology, including head-mounted displays, handheld devices, camera-based systems, and projector-based systems, together with full body manikins or torsos. The common denominator between this research is the goal of enhancing realism of patient interaction for students in a learning environment.

The use of projector-based AR systems with manikins in education is, in the authors' opinion, not a fully explored research area. The advantage of using projectors to display AR to students is that all students observe the same effects without needing extra personal equipment, like they would with head-mounted displays or handheld devices. With the release of projectors specifically designed for AR, new possibilities present themselves in regards to projecting information onto a manikin without having to customise the manikin to fit the projections, which was done in [22] by placing a white fabric mask over the manikin's face.

In this paper the AR projector, Lightform 2 [19], is mounted above a Nursing Anne Simulator manikin [16] used by the nursing education at The Arctic University of Norway, campus Narvik. The main goal of the research is to study the AR projector and its ability to add an extra layer of realism to the manikin in a simulation setting. A focus is given to the results of the projections, the usability, the performance and the limitations of the technology in simulation, and how it compares to similar setups that are not specifically designed for AR.

2 Related work

Research on AR has been, and is being, conducted in many different areas connected to health care and education. Therefore, the related work will concentrate on the use of AR together with manikins in health care, where the focus of the work is education and training. The research has been divided into four paragraphs, based on the utilised technology: head-mounted displays (HMDs), handheld devices, camera-based systems, and projector-based systems.

AR viewed through head-mounted displays is the most common use of AR in health care training. Early research in this area combined HMDs with manikins that were specifically developed with an AR extension in mind. Two examples of this was the Visible Korean Human Phantom [5] and the Mixed Reality Humans [15]. Other research with HMDs can be divided into two groups: Research to complement the manikin and research to enhance the manikin. Research to complement the manikin means that AR is used "next to" a manikin to visualise and give more information. In [28] and [9] videos of a patient experiencing an acute respiratory deterioration was played for students as they entered a room to care for a manikin, and throughout the simulation. Balian et al. [4] used explanatory text and a holographic circulatory system next to a manikin to create a more interactive learning experience for CPR training. This provided the participants with real-time audio-visual feedback via a holographic overlay of blood flow to vital organs while performing CPR. Text was also used in [13], together with images and short gifs, to educate health care professionals on central venous catheter placement. Research to enhance the manikin means that AR is superimposed onto the manikin to make it more realistic. Liang et al. [17] created 3D models with animations of stroke symptoms and projected it onto the head of the manikin. While Rochlen et al. [23] and Brunzini et al. [7] used 3D images for training needle insertion, central venous catheter placement and lumbar puncture, respectively.

One of the early examples of using hand-held devices for AR in health care education is from 1998 where it was applied to manikins in surgical education to produce the illusion of seeing objects "inside" a patient [6]. This Image Overlay prototype system used a semi-transparent display, placed between the surgeon and the manikin, together with a position tracking system, to add 3D images to the manikin regardless of the surgeons position. In 2014 Sheffield Hallam University introduced AR into the nursing and midwifery curriculum to improve the patient experience [3]. Computer generated images and videos of actors were superimposed onto manikins via an iPad tablet to test the students reactions and patient communication skills. The same year the development of Augmented Reality Integrated Simulation Education (ARISE) started [8]. The ARISE project combined AR with game-based situated learning theory and created scenarios for health care students using iPads, QR codes and manikins.

A camera-based AR system was proposed by Sutherland et al. [26] for spinal needle insertion training. The system combined a manikin torso, a MicronTracker camera, and a PHANToM haptic device to provide the user with a physical reference point for a virtual operation, with visual feedback through a monitor.

The use of projectors to create lifelike appearances on manikins goes back to the 1920's when G. Jalbert patented an invention that could be placed in front of, or inside a manikin, to project images onto a screen constituting parts of the manikin [14]. This type of technology was later exploited in health care education. In [22] projectors were used for life support training to give student feedback based on their actions during a simulation. Images were projected onto a white fabric mask on the manikin to create facial expressions synchronised with sound, and body injuries were projected on the waistcoat. A similar study was done in [21] to provide real-time interactive visual feedback in CPR training.

Here a projector, a camera, and sensors placed inside a manikin created a system that enhanced realism of the simulation, collected data from the manikin and trainee, and displayed information about posture, cardiopulmonary press, and artificial respiration rate in real-time. AR projections have also been used to look "inside" manikins. Samosky et al. [24] designed a system called BodyExplorerAR to enhance the ability to explore anatomy, physiology, and clinical interventions. This system turned the manikin's surface into a display screen and an input device, with possibilities to open a viewport to the "inside" of the manikin and observe the response of medical actions.

3 Methods

In this section the projector technology, setup and rigging of the projector with the manikin, and the test scenarios and design are explained.

3.1 Lightform AR projector

As stated in the introduction the projector used in the research was a Lightform 2 (LF2) AR projector [19, 20], displayed in Figure 1. LF2 is the first projector designed for augmented reality, with a projector, a camera, and a computer built into it. Specifications for the LF2 projector including all components are listed by the Hybrid Atelier [1] and the computer specifications used to run the creator software is shown in Table 1.

Fig. 1: The Lightform AR projector.

LF2 comes with a content creation software, included in the purchase: Lightform Creator [18]. Lightform Creator is paired with the LF2 and uses the projector to create a smart scan of the scene covered by the projector's view. This scan, together with a variety of masking tools, can then be utilised to map effects onto objects in the scene. An example is shown in Figure 2 where effects have been added to eight individual bricks on a wall. The purpose of this figure is to illustrate the functionality of the projector and software combined. The red rectangles are the areas were different effects are applied and run simultaneously. Since the program designed in the creator software is already uploaded to the projector with a set of parameters, it will still work even if the computer is disconnected. It should also be noted that if the projector is moved, the effects will follow, but not track.

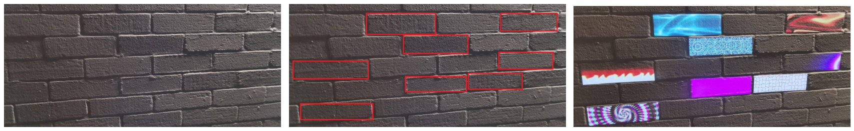

Fig. 2: Eight different effects mapped onto a brick wall with LF2.

Table 1: The computer hardware specifications used with the software and projector.

Computer specifications	
Type	HP EliteBook
GPU	Intel(R) UHD Graphics 620 8 Gb
CPU	Intel(R) Core(TM) i7-8565U CPU @ 1.8 GHz (8 CPUs), 2.0 GHz
RAM	16 Gb
OS	Windows 10 Pro 65-bit

3.2 Setup and rigging

In order for the projector's field of view to cover the correct area of the manikin, and to account for people standing close to it, the projector was placed above the manikin. A custom rig was made with 3D printed parts designed to fit on the adjustable headboard of a bed. On the left in Figure 3 a 3D model of the rig with the projector connected to it is presented and on the right in Figure 3 the final result can be seen with the rig and projector connected to the headboard and the manikin lying in the bed. The projectors field of view was from the top of the head of the manikin and almost down to the knees, with a focus on the manikin's left side. The areas of interest, in this study, to project onto were the face and left thigh of the manikin.

Fig. 3: The rig during the design phase (left) and the final result (right).

3.3 Scenarios and design

To test the projector two main scenarios were chosen in dialog with the nursing education: facial expression and blood flow. They were chosen based on the possibility of using them in a nursing education simulation, to enhance the realism of the manikin in a simulation scenario. For the facial expression the image in Figure 4 was used to simulate a pain expression, and for the blood flow multiple videos were used to simulate a bandage being soaked in blood and blood flowing onto the bed.

Fig. 4: The image projected onto the manikin's face. Obtained from Everypixel.com/melnyk58 [10].

The areas to project the scenarios onto were designed in Lightform Creator. This is done by creating a surface on the Creator scan which the projector is told to paint with light. During the design phase LF2 shows the surface as a white outline that can be edited in real time. An example of the outline is shown in Figure 5 where it was being edited to fit the manikin's face.

Fig. 5: The outline of the surface projected by LF2 onto the manikin.

4 Results

The result of adding the facial expression image to the face of the manikin can be seen in Figure 6, where the left image is the manikin without the projection and the right image is with the projection. By manipulating the design mask and the image to fit the manikin's face, wrinkles and colours were placed correctly to create the desired effect of someone in pain.

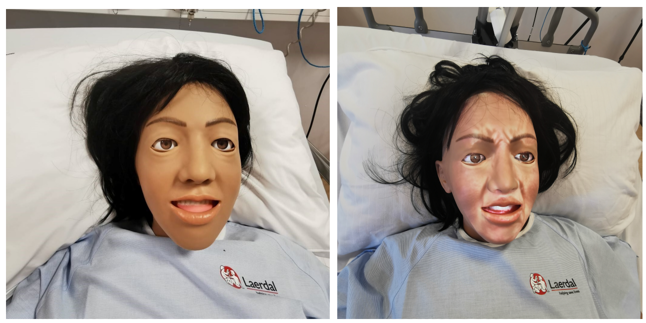

Fig. 6: The manikin before and after projecting a facial expression image onto the face.

The result of the blood flow can be seen in Figure 7 and Figure 8. Two different videos were used. One was placed on the bandage on the manikin's thigh (Figure 7) and the other one on the bed next to the bandage (Figure 8). The videos were played in consecutive order, starting with the video on the thigh, to create the effect of blood flowing from a bandaged wound down in the bed. When the videos were done playing they were replaced with images of the exact moment the videos finished.

Fig. 7: A time series of the blood flow video projected onto a bandage on the manikin's thigh.

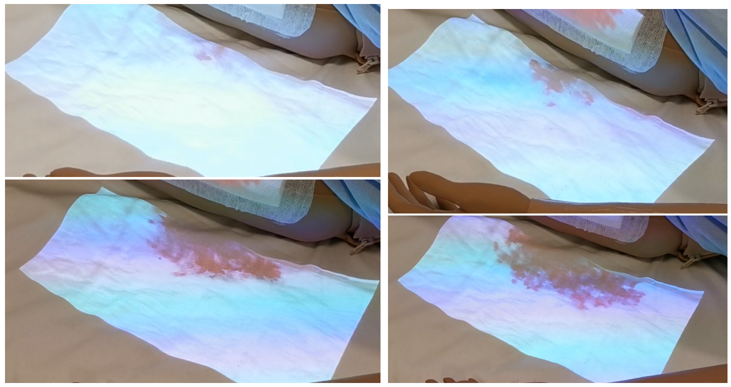

Fig. 8: A time series of the blood flow video projected onto the bed.

5 Discussion

The focus of the discussion will be on the results of the projections, the usability of LF2 and its software, the performance of the projector, limitations that occurred along the way, and how LF2 compares to similar technology.

5.1 Projections

The facial expression projection had positive effect on the manikin in regards to realism. Comparing the before and after images in Figure 6 of the manikin with and without the projections, it can be observed that the projections add some facial features that the manikin does not have. The easiest ones to see are wrinkles and varying skin colour, and also the nasolabial folds are enhanced. Projecting images (or videos) onto the manikin's face to express different emotions offers more flexibility to a simulation scenario, compared to having to change the skin or head of the manikin. By using projections it is possible to switch between expressions during a simulation, based on the development in a scenario or the actions of the students.

The blood flow projections also had positive results. The projected videos were able to create the wanted effects of blood soaking a bandage and spreading out in the bed. Of course the realism in these projections depend heavily on the videos that are used and how physically accurate they are. The videos in this study were filmed with fake blood and look as close to how the result would look during a simulation if fake blood was used on the manikin and bed. By using videos, instead of fake blood, to simulate blood flow on the manikin and the bed, time is saved when running a scenario multiple times, since no cleanup is needed between runs. In addition, no one has to be close to the manikin to start the blood flow because the projections are operated from a computer not connected to the manikin or the bed in any way.

The results of the projections of the facial expression and the blood flow were successfully used in a simulation for second year students at the nursing education, with positive feedback from both staff and students.

5.2 User study

After the design and testing phase of the projector, a user study was performed. The nursing education used the projector setup and tested the two scenarios on their students during a simulation exercise. The results from the simulation were published in [12].

The study involved nursing students who were exposed to AR projections of facial expressions and blood flow on a simulation manikin. The results were gathered through:

- Eleven anonymous, individual, written evaluation forms with open-ended questions.
- Two group discussions involving five to six nursing students per group.
- One interview with the facilitator.

In summary, the study revealed that AR projections on simulation manikins could increase realism and authenticity in nursing simulations. Students observed expressions of pain and blood flow, which improved their experience of patient care and situation handling. Although there were some limitations associated with the technology, the benefits were considered more significant.

5.3 Usability

The software, Lightform Creator, used to create the projections on the manikin was easy to use and intuitive, and it required no programming skills. Scanning the manikin was a straightforward process and the resulting scan was easy to work with. One thing that needed a little more work was to create the areas to add the projections to. Although this was not a complicated task, it was quite time consuming to get the wanted outcome that gave the best results on the manikin. In addition, this task had to be repeated every time the manikin was moved, even for minor movements.

LF2 combined with Lightform Creator create the possibility of applying area-based projections. This means that after a scan is created multiple areas can be covered in different masks that operate independently of each other, and are able to show different projections. For instance, one mask can have an image attached to it while a different mask have a video. The area-based projections offered the opportunity to add different kinds of files to one projection scenario without having to combined them into a single format, and the files did not have to lie side by side.

In Lightform Creator there is a feature that allows for a scenario to be divided into multiple slides. Each slide shows the same scan, but can be fitted with different masks. For instance, slide 1 can have an image projected onto the manikin's face, while slide 2 has the same image as slide 1 and in addition a video projected onto the manikin's thigh. When a scenario is running it is possible to manually jump between slides, or set a slide duration so that when time is up the next slide starts playing. This means that it is possible to set up a scenario, in a simulation setting, that projects different situations depending on time passed or the actions of the students.

5.4 Performance

Both the LF2 projector and the connected computer has not directly been through a time based stress test, but during all our experiments there has been no problems with the up-time (no crashes, no restart or freezing of the projector image). The projector is also capable of showing a scenario without any connected device, and during the simulation for the nursing education the computer turned off for the first 2 hours (sleep mode) while the projector was still on and showing the scenario. Even though this is a short time-frame, the projector was online for the entire session of 8 hours without any errors or hick-ups. A time based benchmark is needed to establish even more convincing evidence for the stability and performance of the projector, but preliminary results are promising.

The projector performed surprisingly well in lit conditions even though it is only using a 1000 lumen bulb. This has been tested in different conditions, ranging from almost pitch black, to a fully operational healthcare scenario room with roof-lights and other light sources. In order for the projector to perform adequately in fully lit conditions, a consideration has to be given to the material projected onto the manikin. Increased room lighting may impose constraints on the choice of images and videos with regard to brightness and colour contrasts. In our experience the projections are only as good as the projected material, regardless of the lighting conditions.

In order to shed light on the performance of the LF2 creator software we refer again to the computer hardware specified in Table 1. When working on multiple slides with several quite large images and videos (4k images and high quality videos) the performance of the software drops drastically, and using the specifications mentioned is not enough to have a smooth user experience and work environment. However, when the user "disables" the images and videos in all slides except one, the performance of the software improves significantly.

5.5 Limitations

During the course of the study three main limitations were discovered: colour change in the projections, movement and vibrations of the manikin and the projector, and fitting images and videos to the manikin and bed. The last limitation arose in the setup phase, while the two first arose during the test phase.

Colour change in the projections occurred when the projector mask was divided into two or more areas, with different files attached to them. An image placed on the manikin's face had a small change in colour tone when adding a video to the thigh, compared to when the video was not present. The image got a reddish hue, which posed a challenge when switching between a scenario where the image was on constantly while the video was only on occasionally. A solution to this that was used in the test phase was to add an "invisible" placeholder video that was turned on when the original video was turned off, so that the image always had a reddish hue.

Since the projector was attached to the bed, and the projections were stationary, movement of the manikin and vibrations from touching the bed caused disturbances in the projections. If the manikin was moved the projections no longer lined up correctly with the face and bandage, while the vibrations made the image and video oscillate for a short period of time before going back to their original place. Both of these challenges, when they occurred, took away some of the realism that the projections were creating.

The last limitation was connected to image and video fitting. There were two challenges in this part: finding appropriate image and videos, and fitting them to the desired areas. The images and videos had to be of high quality, they had to be light, and have a certain amount of contrast between the important features and the rest of the image or video (e.g. wrinkles and blood). Fitting images and videos was mainly a challenge on the manikin's face. This was because the eyes, mouth, and nose had to be taken into account, and be lined up with the same areas in the image and video. An effort was made to create projection masks with holes where the eyes and mouth were on the manikin, however in the end it was observed that the projections were more natural by using an uncut mask.

5.6 LF2 compared to similar technology

During the time frame of this study, the Lightform company has taken the LF2 projector out of their product line and replaced it with a new projector called LF2+. There are very small differences between these two products. The only two changes from LF2 to LF2+ is a better built in camera (improved RGB + IR camera array with 5MP RGB sensor/lens) and an integrated microphone for voice activated commands. Lightform does offer a version (LFC) where only the computer (Lightform hardware specific component) and camera are included and can be connected to a separate self chosen projector. Compared to the new version, the LF2+ would actually be beneficial if a completely new projector was purchased for future research. The microphone is enabling the software to execute different pre-determined commands (in this case change in properties for a given project). These properties include: changing slides, increasing speed of certain effects and starting and stopping the scenario. This type of solution, when already set up, does not require a connection to a computer at all, but instead allows interaction using only voice commands, possibly creating an even better and smoother experience.

In order to create similar technology or solutions as shown in this study, the LF2 projector can be replaced with a suitable projector and camera and a self designed software. It is the software that is responsible for creating suitable projection mapping masks. This solution is already implemented in the Lightform Creator software. One of the advantages of having this type of solution is the ability to swap the projector to experiment with the type and quality of the projection source. This is of course beneficial if a better and more powerful projector is needed, with higher quality images and light emission (lumen). Another solution is to create the entire setup from scratch, and program / design a customised software for specific scenarios. This is a very versatile and open solution, but can of course be very time consuming since nothing is available and pre-made.

6 Conclusions and future work

In this research an AR projector, LF2, was tested together with a Nursing Anne Simulator to study the projector's ability to add an extra layer of realism to the simulator in a simulation setting for the nursing education at The Arctic University of Norway. In addition, a focus was given to the results of the projections, the usability, the performance and the limitations of the technology in simulation, and how it compared to similar setups not specifically designed for AR. The projector was set up with two scenarios: a facial expression image on the manikin's face and two blood flow videos on the manikin's thigh and on the bed. The results showed that the projector-based AR system gave the wanted effect in regards to blood flow and facial expression on the manikin. The usability of the system was straight forward and flexible, and the performance was adequate for the particular use in this study. The system also had some limitations including: colour change in the projections when two or more files were displayed, disturbance in the projections when moving the manikin or the bed, and finding and fitting appropriate images and videos. Lastly, it is worth mentioning that the projections were used successfully in a simulation for second year nursing students, with positive feedback from both staff and students.

The main future work for this research is to eliminate the limitation of not being able to touch or move the manikin and the bed. In order for the AR projections to become a useful part of the nursing education, and to improve simulation realism, this is a key element to solve. Other future works include creating custom made material (images and videos) to fit the manikin and the simulation scenarios better, using multiple projectors with content alignment, edge blending, and synchronised projections to cover more of the manikin or to achieve a brighter projection, and testing the possibility of using videos to project dynamic facial expressions onto the manikin during simulations.

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References

1. Atelier, T.H.: Lightform lf2 projector. https://hybridatelier.uta.edu/equipment/87-lightform-lf2-projecto, accessed: 2024-08-16
2. Azuma, R.T.: A Survey of Augmented Reality. Presence: Teleoperators and Virtual Environments **6**(4), 355–385 (08 1997). https://doi.org/10.1162/pres.1997.6.4.355
3. Baily, L.: Sheffield hallam university uses augmented reality to increase manikin fidelity. https://www.healthysimulation.com/5810/sheffield-hallam-university-uses-augmented-reality-to-increase-manikin-fidelity/ (2014), accessed: 2021-08-20
4. Balian, S., McGovern, S.K., Abella, B.S., Blewer, A.L., Leary, M.: Feasibility of an augmented reality cardiopulmonary resuscitation training system for health care providers. Heliyon **5**(8), e02205 (2019)
5. Bichlmeier, C., Ockert, B., Kutter, O., Rustaee, M., Heining, S.M., Navab, N.: The visible korean human phantom : Realistic test & development environments for medical augmented reality. In: Proceedings of the International Workshop on Augmented environments for Medical Imaging including Augmented Reality in Computer-aided Surgery. AMI-ARCS 2008, USA, New York (2008)
6. Blackwell, M., Nikou, C., DiGioia, A.M., Kanade, T.: An image overlay system for medical data visualization. In: Proceedings of the First International Conference on Medical Image Computing and Computer-Assisted Intervention. p. 232–240. MICCAI '98, Springer-Verlag, Berlin, Heidelberg (1998)
7. Brunzini, A., Papetti, A., Messi, D., Germani, M.: A comprehensive method to design and assess mixed reality simulations. Virtual Reality (02 2022). https://doi.org/10.1007/s10055-022-00632-8
8. Carlson, K.J., Gagnon, D.J.: Augmented reality integrated simulation education in health care. Clinical Simulation in Nursing **12**(4), 123–127 (2016). https://doi.org/https://doi.org/10.1016/j.ecns.2015.12.005, special Issue: Gaming
9. Chaballout, B., Molloy, M., Vaughn, J., Brisson, R., Shaw, R.: Feasibility of augmented reality in clinical simulations: Using google glass with manikins. JMIR Medical Education **2**(1) (2016)
10. Everypixel.com/melnyk58: Close up portrait. https://www.everypixel.com/image-7503555711500516729, accessed: 2021-05-11
11. Gerup, J., Sørensen, C., Dieckmann, P.: Augmented reality and mixed reality for healthcare education beyond surgery: an integrative review. International Journal of Medical Education **11**, 241–258 (01 2020). https://doi.org/10.5116/ijme.5e01.eb1a
12. Høgbakk, M.L., Pedersen, A., Brustad, T.F., Wangberg, S.C.: Utvidet virkelighet gir mer realistisk simulering for sykepleierstudenter. Sykepleien **111** (2023). https://doi.org/10.4220/Sykepleiens.2023.90841
13. Huang, C., Thomas, J.B., Alismail, A., Cohen, A., Almutairi, W., Daher, N., Terry, M.H., Tan, L.D.: The use of augmented reality glasses in central line simulation: "see one, simulate many, do one competently, and teach everyone". Advances in Medical Education and Practice **9**, 357 – 363 (2018)
14. Jalibert, G.: Lay figure. U.S. patent number 1,653,180 (1927)
15. Kotranza, A., Lok, B., Deladisma, A., Pugh, C.M., Lind, D.S.: Mixed reality humans: Evaluating behavior, usability, and acceptability. IEEE Transactions on Visualization and Computer Graphics **15**(3), 369–382 (2009). https://doi.org/10.1109/TVCG.2008.195
16. Laerdal: Nursing Anne Simulator. https://laerdal.com/us/products/simulation-training/nursing/nursing-anne-simulator/, accessed: 2021-08-09

17. Liang, C.J., Start, C., Boley, H., Kamat, V.R., Menassa, C.C., Aebersold, M.: Enhancing stroke assessment simulation experience in clinical training using augmented reality. Virtual Reality **25**(3), 575–584 (2021). https://doi.org/10.1007/s10055-020-00475-1
18. Lightform: Creator - Content Creation Powered by Computer Vision. https://lightform.com/creator, accessed: 2021-08-12
19. Lightform: LF2 - The first AR projector. https://lightform.com/lf2-2, accessed: 2021-08-09
20. Lightform: Lightform - Design tools for projection mapping. https://lightform.com/, accessed: 2021-08-05
21. Park, N., Kwon, Y., Lee, S., Woo, W., Jeong, J.: Projected ar-based interactive cpr simulator. In: Shumaker, R. (ed.) Virtual, Augmented and Mixed Reality. Systems and Applications. pp. 83–89. Springer Berlin Heidelberg, Berlin, Heidelberg (2013)
22. Pretto, F., Manssour, I.H., Lopes, M.H.I., da Silva, E.R., Pinho, M.S.: Augmented reality environment for life support training. In: Proceedings of the 2009 ACM Symposium on Applied Computing. p. 836–841. SAC '09, Association for Computing Machinery, New York, NY, USA (2009). https://doi.org/10.1145/1529282.1529460, https://doi.org/10.1145/1529282.1529460
23. Rochlen, L.R., Levine, R., Tait, A.R.: First person point of view augmented reality for central line insertion training: A usability and feasibility study. Simulation in healthcare : journal of the Society for Simulation in Healthcare **12**(1), 57–62 (2017)
24. Samosky, J.T., Nelson, D.A., Wang, B., Bregman, R., Hosmer, A., Mikulis, B., Weaver, R.: BodyExplorerAR: Enhancing a Mannequin Medical Simulator with Sensing and Projective Augmented Reality for Exploring Dynamic Anatomy and Physiology. In: Proceedings of the Sixth International Conference on Tangible, Embedded and Embodied Interaction. p. 263–270. TEI '12, Association for Computing Machinery, New York, NY, USA (2012). https://doi.org/10.1145/2148131.2148187
25. Sherstyuk, A., Vincent, D., Berg, B., Treskunov, A.: Mixed Reality Manikins for Medical Education, pp. 479–500. Springer New York, New York, NY (2011). https://doi.org/10.1007/978-1-4614-0064-6_23
26. Sutherland, C., Hashtrudi-Zaad, K., Sellens, R., Abolmaesumi, P., Mousavi, P.: An augmented reality haptic training simulator for spinal needle procedures. IEEE Transactions on Biomedical Engineering **60**(11), 3009–3018 (2013). https://doi.org/10.1109/TBME.2012.2236091
27. Tang, K.S., Cheng, D.L., Mi, E., Greenberg, P.B.: Augmented reality in medical education: a systematic review. Canadian Medical Education Journal **11**(1), 81–96 (2020)
28. Vaughn, J., Lister, M., Shaw, R.J.: Piloting augmented reality technology to enhance realism in clinical simulation. CIN: Computers, Informatics, Nursing **34**(9), 402–405 (9 2016)
29. Zhou, F., Duh, H.B.L., Billinghurst, M.: Trends in augmented reality tracking, interaction and display: A review of ten years of ismar. In: 2008 7th IEEE/ACM International Symposium on Mixed and Augmented Reality. pp. 193–202 (2008). https://doi.org/10.1109/ISMAR.2008.4637362
30. Zhu, E., Hadadgar, A., Masiello, I., Zary, N.: Augmented reality in healthcare education: An integrative review. PeerJ **2**, e469 (07 2014). https://doi.org/10.7717/peerj.469
31. Zhu, E., Lilienthal, A., Shluzas, L.A., Masiello, I., Zary, N.: Design of mobile augmented reality in health care education: A theory-driven framework. JMIR Medical Education **1**(2) (2015)