Midwifery 136 (2024) 104064

Contents lists available at ScienceDirect

Midwifery

journal homepage: www.elsevier.com/locate/midw

Augmented reality simulation-based training for midwifery students and its impact on perceived knowledge, confidence and skills for managing critical incidents

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ARTICLE INFO

Keywords:
Midwifery education
Augmented reality
Simulation training
Self-perception
Emergency training
Neonatal resuscitation

ABSTRACT

Problem: Emergency obstetric management is essential in midwifery training to prevent fetal and maternal morbidity. Repeating this management in practice is often not possible. Sustainable confidence in these procedures is usually achieved in the first few years of practice.
Background: Simulation training complements hands-on learning and improves practical skills, benefiting both students and patients. Research on obstetric emergency simulation training have demonstrated this, but the use of digital simulation approaches, such as augmented reality (AR), is under-researched.
Aim: To investigate whether AR simulation training influences midwifery students' subjective perceptions of knowledge, confidence and practical skills in emergency situations.
Methods: A descriptive exploratory study was conducted using a pre-post design. AR scenarios were developed on the topics of 'preparing emergency tocolysis', 'preparing a pregnant woman for caesarean section' and 'resuscitation of newborns'. The AR simulation was conducted in the fourth to fifth semester of the midwifery programme. A questionnaire was developed for students ($N = 133$) to self-assess their competence in the categories of knowledge, confidence and practical skills.
Results: Students rated their competence significantly better in the post-survey than in the pre-survey (p=<0.05). Simulation has an impact on self-assessment of professional knowledge, confidence and practical skills in emergency situations. It enhances students' procedural knowledge and practical skills in complex contexts, complements subject knowledge and builds confidence.
Conclusion: The results provide initial evidence that AR simulation is an effective learning strategy for emergency management preparedness. Future studies should validate the effect with control cohorts and measure competence through practical examinations.

Statement of Significance

Problem or issue	Practising appropriate emergency management is challenging. To achieve competencies, midwifery students need to acquire knowledge, skills, behaviours and self-confidence.
What is already known	Simulation training increases students' confidence and complements hands-on learning. It combines theory and practice, provides a safe learning environment and encourages self-directed learning. Augmented reality (AR) simulations for obstetric emergencies have not yet been researched in midwifery training.
What this paper adds	This paper evaluates an AR-App developed specifically for emergency training of midwifery students. It assesses the impact of this app on subjective perceptions of

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https://doi.org/10.1016/j.midw.2024.104064
Received 15 April 2024; Received in revised form 22 May 2024; Accepted 11 June 2024
Available online 12 June 2024

(*continued*)

	knowledge, self-confidence and practical skills in emergency situations.

Background

Learning about obstetric emergencies and their management is essential not only for midwifery students, but also for working midwives throughout their professional career, to reduce perinatal morbidity and mortality. In addition to the acquisition of practical skills, the management of obstetric emergencies is crucial (International Confederation of Midwives, 2019). Due to the infrequent and unpredictable occurrence of various complications and emergencies, regular practice of procedures often proves to be challenging. In the medical profession, confidence usually develops only during the first few years of working (Ochsmann et al., 2011). Various forms of teaching and learning are available to support the acquisition and transfer of knowledge from theory to practice (Hajian, 2019). In Germany, the bachelor's degree in midwifery takes place in three learning contexts: theory, skills lab and practice. In general, different teaching/learning approaches are used: In theory, for example, problem-based learning is used in addition to traditional formats such as lectures and seminars (Berthold and Bauer, 2020) or web-based training courses. Hands-on sessions in the skills lab teach practical obstetric emergency skills using high-fidelity simulators, enhancing interdisciplinary training for midwifery practice (Löwen and Schlüter-Cruse, 2022). In Germany, midwifery students are required by law to complete a minimum of 2200 h of practical training (Heb, 2019).

In order to become competent, it is important that midwifery students acquire relevant knowledge, skills and behaviours. The concept of competence is embedded in a holistic approach which distinguishes between general competence for support before, during and after childbirth (International Confederation of Midwives, 2019). One aspect of general competence is that the midwife's behaviour contributes to strengthening public confidence in the profession. This requires, in particular, self-confidence, which is described as the ability to act and apply knowledge in practice (Bergen and Santo, 2018). Traditional teaching methods provide students with knowledge and practical skills. The challenge is to foster confidence in students' abilities, a key psychological concept which involves recognising one's own abilities and emotions (Kukulu et al., 2013). Thus, it is a relevant competence which entails continuous self-reflection and self-assessment (Kordi et al., 2015). In particular, professional confidence is considered to be one of the most important components of clinical competence with a major impact on the practical skills and competence of midwives and nurses (Kukulu et al., 2013). To increase student's confidence, the World Health Organization (WHO, 2018) recommends the use of simulation learning in midwifery education. Simulation-based learning can complement practice-based learning and have a positive impact on the skills required in clinical practice. It therefore benefits not only students but patients also (WHO, 2018). Simulation training can help bridge the gap between theory and practice, especially in emergency situations. It provides a safe learning environment and enables self-directed and experiential learning, in addition to effective preparation for practice (Miller et al., 2015; Lendahls and Oscarsson, 2017).

Simulation training

Simulation, an innovative approach to learning, is used in midwifery education. It includes different types, including low-fidelity simulations using basic models to teach basic skills, and high-fidelity simulations using computerised full-body simulators, such as full-body birth simulators (WHO, 2018). Hybrid simulations combine anatomical models with actors simulating patients to create realistic scenarios. Virtual fidelity simulations use computer-generated images combined with audio and visual stimuli to create an immersive learning experience. Role-playing is a further method, in which actors play patients in order to simulate realistic situations. Each of these simulation techniques has its own benefits, helping participants to practise and deepen different aspects of the subject matter in a variety of ways (Cooper et al., 2012; WHO, 2018). The required skills are considered to determine the most appropriate type of simulation. Low-fidelity simulations emphasise knowledge and psychomotor skills, while high-fidelity simulations focus on communication, clinical decision-making, teamwork and accountability (Brady, 2013; WHO, 2018).

The extent to which training is embedded in teaching and learning contexts varies widely. In the medical field, for example, simulation units, lectures, video demonstrations, online elements and practical workshops are combined (Carolan-Olah et al., 2016; Stoodley et al., 2020). Training provides a safe environment for the development of practical skills, allowing participants to learn from mistakes without adversely affecting patients (Changuiti et al., 2023). In the context of midwifery education, the courses have been shown to help link theoretical knowledge with practice (Lendahls and Oscarsson, 2017; Maskálová et al., 2018). In particular, inexperienced participants showed an increase in their practical skills compared to experienced practitioners (Malmström et al., 2017), and a significant increase in sense of security (Stoodley et al., 2020; Changuiti et al., 2023) and confidence (Vermeulen et al., 2017). Simulation training motivates participants to interact and cooperate, and studies of multidisciplinary groups show that it improves soft skills such as communication and teamwork (Changuiti et al., 2023). Traditionally conducted in skills labs, advances in technology offer new opportunities for innovative digital teaching methods.

Web-based training is a precursor to AR-based training, providing an innovative digital learning environment that lays the groundwork for distance learning, paving the way for immersive, interactive teaching methods (Adams Becker et al., 2018). Kordi et al. (2016) suggest that web-based training can serve as an alternative or complementary method to improve the accuracy of certain skills.

The use of mixed reality (MR) technologies (Milgram et al., 1995), virtual reality (VR) and AR for simulation training enable the development of self-directed simulation approaches that create immersive and realistic learning environments (Dalim et al., 2017).

MR is a family of technologies on the reality-virtuality continuum which visually and aurally mixes reality with computer-based content (Milgram et al., 1995). While virtual reality provides immersive training in entirely computer-generated environments, augmented reality augments the real world with computer-generated content. This augmentation can take place through head-mounted displays or handheld devices such as smartphones and tablets. The latter are cheaper and more accessible to learners, as they can use personal devices, thus encouraging self-directed and location-independent learning through familiar interaction metaphors (Blattgerste et al., 2021).

MR approaches are characterised as a key technology for experience-based learning scenarios which could not be implemented in traditional teaching (Adams Becker et al., 2018).

Recent reviews examine in particular the use of simulations in general practice education (Svendsen and Achiam, 2022; Wu et al., 2022). Compulsory participation correlates with reduced learning and acceptance of virtual simulations. Evaluations of virtual simulations among medical students are generally positive and cover a range of areas, including surgical procedures, emergency medicine, basic skills, medical imaging, paracentesis and interprofessional education. However, challenges remain in terms of accessibility of resources, infrastructure and student motivation (Wu et al., 2022). In addition, immersive simulation training in life-saving procedures has been shown to have a positive impact on students' confidence, especially in real-life, stressful situations with potentially life-threatening consequences (McKelvin and McKelvin, 2020). Students consistently respond positively to VR simulations, finding them educational, engaging and conducive to safe, self-directed learning. Emphasis is placed on avoiding potential patient harm. Recommendations highlight the versatility of VR, from practising clinical skills to preparing for placements and exploring rare clinical scenarios (Saab et al., 2023).

Midwifery education focuses on improving practical skills and safety in real clinical scenarios. While simulation training for obstetric emergencies has been studied, there's still very little analysis of newer approaches such as AR, the integration of which could advance practical and future-oriented midwifery education.

Research question

Based on the aforementioned problem, the present study aims to investigate whether practising with AR simulation training has an influence on midwifery students' subjective perception of their knowledge, confidence and practical skills in emergency situations.

Methods

Project description

The project Heb@AR developed three AR scenarios for midwifery education: 'preparing emergency tocolysis', 'preparing a pregnant woman for caesarean' and 'resuscitation of newborns'. These scenarios were integrated into midwifery training curricula after extensive usability testing (Blattgerste et al., 2021). The AR interactions are accessible through the Heb@AR app on iOS and Android smartphones (Blattgerste et al., 2020; 2021), allowing for a 'bring your own device' approach. No additional equipment (e.g. smart glasses) is required, the app runs on all mid-range smartphones (manufactured from 2019 onwards and with AR support), minimising costs. Development of the AR simulations was based on the International Nursing Association's Healthcare Simulation Standards of Best Practice™ guidelines for clinical simulation and learning (Watts et al., 2021).

Intervention: description of AR scenarios

The AR simulation 'preparing emergency tocolysis' focuses on the professional preparation of a mixture of a tocolytic drug and a carrier solution to be administered intravenously according to the doctor's instructions. As part of the AR scenario, students learn how to prepare the emergency medication using a specific case study. The entire procedure (preparation - execution - follow-up) is performed virtually. Training can be conducted anywhere, without materials (see Fig. 1).

The AR simulation 'preparing a pregnant woman for caesarean section' focuses on the placement of an indwelling urinary catheter. The other learning objectives for preparing a pregnant woman for caesarean section are developed using blended e-learning strategies. AR training in the skills lab reinforces theoretical knowledge and practical skills by providing a realistic environment with simulators and all necessary catheterisation equipment (see Fig. 1).

The AR simulation 'resuscitation of newborns' teaches resuscitation skills following the 2021 European Resuscitation Council (ERC) guidelines (Madar et al., 2021). Practical skills such as stethoscope use, resuscitation bag handling and chest compression are emphasised. The Neonatal Resuscitation scenario is available in single-user and multi-user (up to six people) versions, including a skills lab version (see Fig. 1).

In addition to the materials mentioned, an 'AR Marker' is required for the scenarios 'preparing a pregnant woman for caesarean section' and 'resuscitation of newborns'. This can be downloaded and printed free of charge from the Heb@AR app under the menu item 'Instructions & Utensils'.

All sessions have consistent elements for effective learning. They begin with a technical briefing on the use of smartphones, provide access to expert advice from an virtual lecturer, and end with written feedback to the learner. Students receive automatically generated feedback at the end of the simulation. This is done graphically by categorising the performance as 'improvable', 'good' and 'very good'. The time taken is reported, as are errors and important correct steps (Blattgerste et al., 2021). Different interaction concepts are used: In the '@home' variation, users trigger actions on their smartphones by interacting with virtual objects and can pick up and combine materials and start user-defined actions, e.g. a quiz on the correct labelling of an emergency tocolysis) (Blattgerste et al., 2021). During the simulations in the skills lab, interaction follows the decide-freeze-imitate model: students select an action, receive feedback, then see the action in AR, perform it without a smartphone, and pick it up (the smartphone) again. There are also user-defined actions, such as documenting the placement of an indwelling urinary catheter (Blattgerste, 2024).

Fig. 1. The three AR simulation (Heb@AR) scenarios: On the left you can see the scenario 'preparing emergency tocolysis'. It is performed without any materials on a table or worktop. The student is holding her smartphone, which displays the AR materials on the worktop. In the middle is a screenshot of the smartphone with the scenario 'preparing a pregnant woman for caesarean section', which focuses on the placement of an indwelling urinary catheter. The correct sequence for disinfecting the skin and mucous membranes is shown on the smartphone. The 'resuscitation of newborns' scenario is shown on the right. Here, the smartphone is set aside according to the decide-freeze-imitate model and the action is performed. Meanwhile, the smartphone continues to display the correct action and the frequency of the action, both visually and audibly.

Curricular implementation

The AR scenarios were used in the fourth and fifth semesters (the course typically takes seven to eight semesters to complete, depending on the university) of the undergraduate midwifery programme. The simulation was integrated into the curriculum. However due to the Covid-19 pandemic, attendance was not compulsory. Students received lectures, seminars and exercises based on the principle of problem-based learning, with practical skills learned in the skills lab. The focus was on specific skills, such as the correct mask ventilation of a newborn. Later, asynchronous online events, such as web-based trainings, were available to support and consolidate independent learning, with the AR training simulation introduced as the final element (see Fig. 2). In the skills lab, the exercises were facilitated by a midwifery lecturer trained in AR applications. These AR-supported exercises were designed to deepen and practise the knowledge from the previous courses in complex situations. This structure was designed not only to enhance the students' understanding but also to strengthen the application of their knowledge in realistic situations.

Study design

This is a descriptive exploratory study with a pre-post treatment design. Students completed online questionnaires before and immediately after the AR training. The pre-survey was conducted before the preliminary discussion and the AR simulation, while the post-survey was conducted immediately after the AR simulation, before the debriefing. The intervention was conducted between 2021 and 2023 in four study cohorts at three different universities in Germany. The survey took place at the end of the fourth or at the beginning of the fifth semester.

Survey instrument

An exploratory online questionnaire was developed based on the approach of Stoodley et al. (2020). The categorisation of skills on a 5-point Likert scale and the level of self-assesment in relation to the learning objectives were adapted according to categories of knowledge, confidence and practical skills (Stoodley et al., 2020).

Each student chose a unique pseudonym in order to be able to correlate the assessment of learning status before and after the intervention and to guarantee respondent anonymity. The questionnaire was thematically adapted to the respective simulation, with the self-assessment evaluated according to the defined learning objectives (see Table 1 for sample questions). The first questionnaire for the AR simulation 'preparing emergency tocolysis' contained 6 items for 2 learning objectives, taking around 4 min to complete. The second questionnaire 'preparing a pregnant woman for caesarean section' had 9 items covering 3 learning objectives, duration about 6 min. The 'resuscitation of newborns' questionnaire had 21 items covering 7 learning objectives and took approximately 16 min to complete. Each questionnaire underwent pre-screening for consistency and clarity by the project team and a pre-test using the think-aloud method (Ericsson and Simon, 1998), with two non-intervention group students.

Table 1
Example of Likert scale question.

In the following section, we ask you to rate the following statements in terms of your knowledge, confidence and practical skills:

	very low	low	moderate/ medium	high	very high
How would you rate your (theoretical) **knowledge** of the procedure for the preparation, administration and follow-up of emergency tocolysis?	☐	☐	☐	☐	☐
How would you rate your **confidence** in performing the procedure for the preparation, administration and follow-up of emergency tocolysis?	☐	☐	☐	☐	☐
How would you rate your **practical skills** regarding the procedure for the preparation, administration and follow-up of emergency tocolysis?	☐	☐	☐	☐	☐

Data preparation

Pre- and post-survey data was merged in SPSS (version 29) prior to analysis. Only questionnaires from students who participated in both surveys were included. A four-step data preparation process was used to check the quality of the data: (1) the data was examined for anomalies or patterns in ticking behaviour. (2) This was followed by a frequency count of all variables, where the mean, standard deviation, median, mode, minimum and maximum were checked for plausibility. (3) Next, the variance across all blocks of the questionnaire was analysed. Any anomalous records identified were checked manually and in the final step (4) the processing time was assessed. If it was significantly below average, the questionnaires (pre- and post-survey) were excluded from the analysis.

Data analysis | Pre- and post-survey

Quantitative data were analysed descriptively using SPSS statistical and analysis software. In addition, data from the pre-post survey were analysed using a dependent samples *t*-test. Cohen's Classification was used to assess the strength of the effect (Cohen, 1988).

Results

A total of 133 students took part in the AR simulation in the study period (2021–23). The number of participants varies between the scenarios of the AR simulation due to the uneven distribution of students in the exercises.

Preparing emergency tocolysis

55 students participated in the AR intervention and all questionnaire

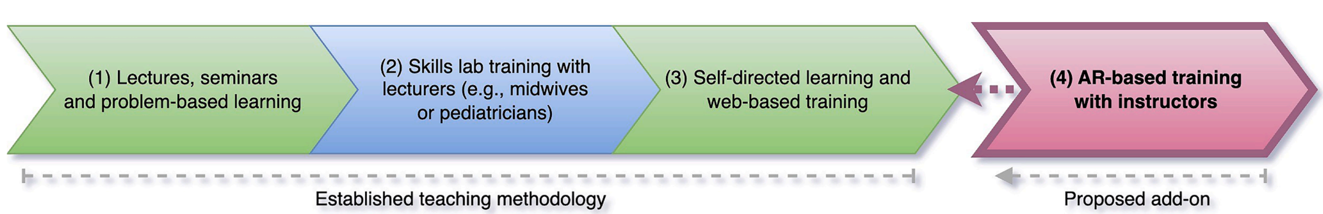

Fig. 2. Curricular implementation of the AR simulation

pairs were included in the analysis.

The AR scenario 'preparing emergency tocolysis' addressed two learning objectives: (1) to perform the procedure for the preparation, administration and follow-up of emergency tocolysis and (2) application of hygiene and occupational safety measures.

On average, students rated their knowledge, confidence and practical skills in relation to the two learning objectives as low to moderate overall before the AR simulation. After the simulation, however, they tended to rate these as high. The results of the pre-post survey are significant in all categories for each learning objective (p=<0.01). The results with the strongest characteristics are considered in more detail below; all other results can be found in Table 2.

With regard to the first learning objective, students reported the most significant changes in terms of learning progress. Self-assessment of theoretical knowledge demonstrated a clear improvement from 2.56 (low) pre-, to 4.00 (high) post-simulation training (T = −9.821, p=<0.001). The effect size of 1.085 indicates a large effect according to Cohen. At the same time, students' perception of confidence in the execution of the action improved from 2.44 (low) to 3.91 (moderate) after the simulation (T = −9.224, p=<0.001), again indicating a large effect size (1.184). There was also an increase in practical skills from 2.85 (low) pre-simulation to 3.91 (moderate) post-simulation (T = −9.222, p=<0.001). The Cohen's d value of 0.848 again indicates a large effect.

Preparing a pregnant woman for caesarean section - Focus: placement of an indwelling urinary catheter

92 students participated in the AR intervention. A total of 78 (84.78 %) pairs of questionnaires were included in the analysis.

In the context of this AR scenario, three specific learning objectives were emphasised: (1) the correct placement of an indwelling catheter (IDC), (2) the preparation of a pregnant woman for an urgent caesarean section with a 30 min decision to delivery, and (3) administration (file check: surgery and anaesthesia information, documentation, surgery protocol).

Students initially rated their theoretical knowledge, confidence and practical skills as low overall, with one category being moderate. After the AR simulation, ratings improved to moderate in all categories, showing significant improvements in each learning objective (p=<0.01). The results with the strongest characteristics are discussed in detail below; all other results can be found in Table 3.

The training focus of the AR simulation was primarily on learning objective (1) correct placement of an IUC. Participants' perception of confidence increased from a mean of 2.92 (low) pre-simulation to 3.60 (moderate) post-simulation (T = −6.002, p=<0.001). A Cohen's d of 1.000 indicates a large effect size. Students' practical skills assessment also showed an improvement, with the mean score increasing from 2.91 (low) pre-, to 3.53 (moderate) post-simulation (T = −6.034, p=<0.001), also with a large effect size (0.901).

Perception of confidence for learning objective (2) preparation of a pregnant woman for an urgent caesarean section also increased, from a mean of 2.69 (low) pre-, to 3.24 (moderate) post-simulation (T = −6.493, p=<0.001). The Cohen's d value of 0.75 indicates a moderate effect. Students' practical skills also improved, with the mean score rising from 2.85 (low) pre- to 3.29 (moderate) post-simulation (T = −5.167, p=<0.001). With an effect size of 0.767, this indicates a medium effect.

Resuscitation of newborns

106 students participated in this AR intervention. A total of 101 (95.28 %) pairs of questionnaires were included in the analysis.

The AR scenario addressed a total of seven learning objectives for the professional implementation of neonatal resuscitation. They included (1) application of the ERC resuscitation guidelines, (2) application of the algorithm according to the ERC guidelines, (3) implementation of effective thermal management in initial care, (4) (initial) assessment of the newborn, (5) implementation of manual ventilation, (6) performance of chest compression and (7), monitoring with pulse oximetry and ECG.

Before completing the AR simulation, the students rated their knowledge, confidence and practical skills on average as low to moderate. After the training, they rated them in most categories as moderate and in one as high. The results of the pre-post survey are significant in all categories for each learning objective (p=<0.01). The results with the strongest characteristics are presented below; all other results can be found in Table 4.

In the first learning objective (application of ERC guidelines for resuscitation) the students demonstrated an improved perception of confidence; from 2.80 (low) pre-simulation to 3.42 (moderate) afterwards (T = −7.715, p =<0.001). This indicates a strong Cohen's effect size of 0.8. Practical skills also showed a significant improvement, from a mean of 2.92 (low) pre-simulation to 3.38 (moderate) post-simulation (T = −6.169, p =<0.001); Cohen's effect 0.742, moderate.

Learning objective (4) of the (initial) assessment of the newborn shows similar results. The most significant changes were seen in the assessment of practical skills and perceived confidence. For the perception of confidence, the mean score improved from 2.84 (low) pre-simulation to 3.40 (moderate) post-simulation (T = −7.517, p=<0.001). The Cohen's d value of 0.741 indicates a moderate effect. Similarly, students' practical skills improved significantly, with the mean score increasing from 2.93 (low) pre-simulation to 3.41 (moderate) post-simulation (T = −5.742, p=<0.001), and a large effect size of 0.832.

For learning objective (5) implementation of manual ventilation, the clearest effects were also found in the perception of confidence and assessment of practical skills. Perception of confidence improved from 2.92 (low) pre-simulation to 3.57 (moderate) post-simulation (T = −7.59, p=<0.001), with the Cohen's d value of 0.865 indicating a large effect. Students' practical skills likewise with the mean score rising from 2.91 (low) pre-simulation to 3.48 (moderate) post-simulation (T = −7.155, p=<0.001), and an effect size indicative of a moderate effect (0.793).

With regards to learning objective (6), performing chest

Table 2
Assessment of students' theoretical knowledge, perception of confidence and practical skills in 'preparing emergency tocolysis', *t-test.

	Pre-simulation n = 55		Post-simulation n = 55		Pre-post simulation				
	Mean (SEM)	SD	Mean (SEM)	SD	Mean (SEM)	SD	T (df)	Coefficient (CI; p)	Cohen's d
(1) Perform the procedure for the preparation, administration and follow-up of emergency tocolysis									
Knowledge	2.56 (0.1)	.958	4.00 (0.1)	.638	−1.436 (0.2)	1.085	−9.821 (54)	(−1.730 −1.143; p=<0.001)	1.085
Confidence	2.44 (0.1)	.938	3.91 (0.1)	.752	−1.473 (0.2)	1.184	−9.224 (54)	(−1.793 −1.153; p=<0.001)	1.184
Skills	2.85 (0.1)	.931	3.91 (0.1)	.701	−1.055 (0.1)	.848	−9.222 (54)	(−1.284 −0.825; p=<0.001)	0.848
(2) Application of hygiene and occupational safety measures									
Knowledge	3.80 (0.1)	.650	4.05 (0.1)	.621	−0.255 (0,1)	.673	−2.806 (54)	(−0.436 −0.073; p=0.007)	0.673
Confidence	3.73 (0.1)	.651	4.16 (0.1)	.631	−0.436 (0,1)	.877	−3.690 (54)	(−0.673 −0.199 p=<0.001)	0.877
Skills	3.75 (0.1)	.615	4.13 (0.1)	.668	−0.382 (0,1)	.680	−4.163 (54)	(−0.566 −0.198; p=<0.001)	0.680

Rating scheme: 1= very low, 2= low, 3= moderate/medium, 4= high, 5= very high.

Table 3
Assessment of students' theoretical knowledge, perception of confidence and practical skills in 'preparing a woman for caesarean section, *t-test.

	Pre-simulation $n = 78$		Post-simulation $n = 78$		Pre-post simulation				
	Mean (SEM)	SD	Mean (SEM)	SD	Mean (SEM)	SD	T (df)	Coefficient (CI; p)	Cohens' d
(1) Correct placement of an indwelling urinary catheter (IDC)									
Knowledge	3.42 (0.1)	.814	3.71 (0.1)	.723	−0,282 (0.1)	.896	−2.781 (77)	(−0.484 −0.080; p=0.007)	0.896
Confidence	2.92 (0.1)	1.016	3.60 (0.1)	.843	−0.679 (0.1)	1.000	−6.002 (77)	(−0.905 −0.454 p=<0.001)	1.000
Skills	2.91 (0.1)	.956	3.53 (0.1)	.817	−0.615 (0.1)	.901	−6.034 (77)	(−0.818 −0.412 p=<0.001)	0.901
(2) Preparation of a pregnant woman for an urgent caesarean section (decision - delivery time 30 min)									
Knowledge	2.94 (0.1)	.795	3.36 (0.1)	.789	−0.423 (0.1)	.782	−4.781 (77)	(−0.599 −0.247; p=<0.001)	0.782
Confidence	2.69 (0.1)	.887	3.24 (0.1)	.856	−0.551 (0.1)	.750	−6.493 (77)	(−0.720 −0.382; p=<0.001)	0.750
Skills	2.85 (0.1)	.884	3.29 (0.1)	.775	−0.449 (0.1)	.767	−5.167 (77)	(−0.622 −0.276; p=<0.001)	0.767
(3) Administration (file check: surgery and anaesthesia information, documentation, surgery protocol).									
Knowledge	2.77 (0.1)	.867	3.06 (0.1)	.779	−0,295 (0.1)	.808	−3.225 (77)	(−0.477 −0.113; p=0.002)	0.808
Confidence	2.63 (0.1)	.824	3.01 (0.1)	.814	−0.385 (0.1)	.760	−4.470 (77)	(−0.556 −0.213; p=<0.001)	0.760
Skills	2.67 (0.1)	.784	3.01 (0.1)	.781	−0.346 (0.1)	.661	−4.624 (77)	(−0.495 −0.197; p=<0.001)	0.661

Rating scheme: 1= very low, 2= low, 3= moderate/medium, 4= high, 5= very high.

Table 4
Assessment of students' theoretical knowledge, perception of confidence and practical skills in 'resuscitation of newborns', *t-test.

	Pre-simulation $n = 101$		Post-simulation $n = 101$		Pre-post-simulation				
	Mean (SEM)	SD	Mean (SEM)	SD	Mean (SEM)	SD	T (df)	Coefficient (CI; p)	Cohens's d
(1) Application of the ERC resuscitation guideline									
Knowledge	3.21 (0.1)	0.753	3.45 (0.1)	0.640	−0.238 (0.1)	0.777	−3.075 (100)	(−0.391 −0.084; p=0.003)	0.777
Confidence	2.80 (0.1)	0.849	3.42 (0.1)	0.697	−0.614 (0.1)	.800	−7.715 (100)	(−0.772 −0.456; p=<0.001)	0.800
Skills	2.92 (0.1)	0.783	3.38 (0.1)	0.646	−0,455 (0.1)	.742	−6169 (100)	(−0,602 −0,309; p=<0.001)	0.742
(2) Application of the ERC guideline algorithm									
Knowledge	3.25 (0.1)	0.727	3.46 (0.1)	0.671	−0.208 (0.1)	.753	−2.777 (100)	(−0.356 −0.059; p=0.007)	0.753
Confidence	2.92 (0.1)	0.821	3.40 (0.1)	0.649	−0.475 (0.1)	.769	−6.208 (100)	(−0.627 −0.323; p=<0.001)	0.769
Skills	2.88 (0.1)	0.778	3.41 (0.1)	0.651	−0.525 (0.1)	.782	−6.742 (100)	(−0.679 −0.370; p=<0.001)	0.782
(3) Implementation of effective thermal management in initial care									
Knowledge	3.76 (0.1)	0.723	4.03 (0.1)	0.670	−0.267 (0.1)	.615	−4.371 (100)	(−0.389 −0.146; p=<0.001)	0.615
Confidence	3.61 (0.1)	0.721	3.95 (0.1)	0.767	−0.337 (0.1)	.725	−4.667 (100)	(−0.480 −0.194; p=<0.001)	0.725
Skills	3.57 (0.1)	0.669	3.93 (0.1)	0.725	−0.356 (0.1)	.701	−5.109 (100)	(−0.495 −0.218; p=<0.001)	0.701
(4) (Initial) assessment of the newborn									
Knowledge	3.15 (0.1)	0.669	3.51 (0.1)	0.702	−0.366 (0.1)	.689	−5.345 (100)	(−0.502 −0.23; p=<0.001)	0.689
Confidence	2.84 (0.1)	0.745	3.40 (0.1)	0.708	−0.554 (0.1)	.741	−7.517 (100)	(−0.701 −0.408; p=<0.001)	0.741
Skills	2.93 (0.1)	0.652	3.41 (0.1)	0.777	−0.475 (0.1)	.832	−5.742 (100)	(−0.639 −0.311; p=<0.001)	0.832
(5) Implementation of manual ventilation									
Knowledge	3.34 (0.1)	0.816	3.66 (0.1)	0.803	−0.327 (0.1)	.896	−3.666 (100)	(−0.504 −0.150; p=<0.001)	0.896
Confidence	2.92 (0.1)	0.880	3.57 (0.1)	0.792	−0.653 (0.1)	.865	−7.590 (100)	(−0.824 −0.483; p=<0.001)	0.865
Skills	2.91 (0.1)	0.826	3.48 (0.1)	0.743	−0.564 (0.1)	.793	−7.155 (100)	(−0.721 −0.408; p=<0.001)	0.793
(6) Performing chest compression									
Knowledge	3.45 (0.1)	0.793	3.72 (0.1)	0.709	−0.277 (0.1)	.750	−3.715 (100)	(−0.425 −0.129; p=<0.001)	0.750
Confidence	3.08 (0.1)	0.845	3.58 (0.1)	0.711	−0.505 (0.1)	.757	−6.707 (100)	(−0.654 −0.356; p=<0.001)	0.757
Skills	3.10 (0.1)	0.806	3.55 (0.1)	0.768	−0.455 (0.1)	.755	−6.060 (100)	(−0.605 −0.306; p=<0.001)	0.755
(7) Monitoring with pulse oximetry and ECG.									
Knowledge	3.22 (0.1)	0.934	3.86 (0.1)	0.749	−0.644 (0.1)	.944	−6.849 (100)	(−0.830 −0.457; p=<0.001)	0.944
Confidence	3.08 (0.1)	1.017	3.94 (0.1)	0.732	−0.861 (0.1)	.917	−9.442 (100)	(−1.042 −0.680; p=<0.001)	0.917
Skills	3.09 (0.1)	0.971	3.89 (0.1)	0.773	−0.802 (0.1)	.800	−10.072 (100)	(−0.960 −0.644; p=<0.001)	0.800

Rating scheme: 1= very low, 2= low, 3= moderate/medium, 4= high, 5= very high.

compression, improvements were also demonstrated, despite scores remaining within the moderate range. Perception of confidence increased from 3.08 to 3.58 ($T = -6.707$, p=<0.001), Cohen's d value 0.757. In terms of practical skills, the mean score remained moderate, but increased from 3.10 to 3.55 ($T = -6.06$, p=<0.001), Cohen's (0.755) also indicating a moderate effect.

Similarly, in learning objective (7) monitoring the students showed an increase in knowledge from 3.22 to 3.86 remained within the moderate range ($T = -6.8495$, p=<0.001), while the Cohen's d value of 0.944 indicates a large effect. Students' perceptions of confidence also improved within the moderate range, from 3.08 to 3.94 ($T = -9.442$, p=<0.001), and a further large effect indicated by the Cohen's d value of 0.917. Again, in terms of practical skills the mean score also increased within the moderate range from 3.09 to 3.89 ($T = -10.072$, p=<0.001), and an effect size of 0.8 indicating a large effect.

Discussion

The analysis shows that AR simulation training has a positive impact on participants' knowledge, confidence and competence in performing practical skills in emergency situations. Evaluations completed immediately after the training show a significant positive learning effect in all scenarios.

The AR simulation 'preparing emergency tocolysis' aimed to deepen procedural knowledge. Self-assessment indicates that this occurred at all levels (knowledge, confidence and practical skills), particularly with regard to the learning objective of consolidating procedures. Esposito and Sullivan (2020) also found AR simulation to be a useful method of reinforcing knowledge and skills, particularly in healthcare professions. The ability to complete the AR 'preparing emergency tocolysis' training programme at home makes it a promising option for self-directed learning. This flexibility in terms of location and accessibility provide an advantage over traditional face-to-face learning programmes or high-fidelity approaches which rely on the appropriate setting and equipment: No lecturer is needed for the training of simpler scenarios where procedural learning is key and no materials are required. Even in times of global pandemics such as Covid-19, AR simulations are a promising approach to ensuring learning despite safety precautions. Tasks which are often performed under time pressure, such as medication preparation, permit self-directed learning, which increases the learner's confidence and awareness. The AR simulations 'preparing a pregnant woman for caesarean section' (focusing on the placement of an IDC) and 'resuscitation of newborns' focused on training procedural knowledge, strengthening decision-making skills and improving practical skills. Both courses showed a clear improvement in perceived ability to act. In particular, participants found that the AR simulation for 'resuscitation of newborns' facilitated the development of skills in monitoring, performing chest compression and manual ventilation and the application of resuscitation algorithms. Previous research has found that AR simulation training for emergency situations has a positive effect on participants' confidence (Kumar et al., 2015; Carolan-Olah et al., 2016; Stoodley et al., 2020), and in other investigations, serious game simulations have led to significant improvements in ventilation and chest compression skills (Demirtaş et al., 2022; Sarvan and Efe, 2022). The integration of such training methods into curricula enables targeted improvement in the performance of future healthcare professionals in resuscitation techniques. A further benefit is that the use of AR training scenarios relieves the teaching staff; while the scenario guides participants through the resuscitation algorithm, teaching staff can concentrate on observing and teaching individual techniques, as confirmed in research by Lendahls and Oscarsson (2017) and Maskálová et al. (2018). Particularly in the two complex scenarios ('neonatal resuscitation' and 'preparing a pregnant woman for caesarean section'), self-direction combined with guidance from experienced lecturers was found to be highly effective, especially given the potentially emotional outcomes of such simulations as neonatal resuscitation, emphasising the importance of lecturer-led debriefing. The growing acceptance of innovative training, particularly in neonatology, obstetrics and other medical fields, underlines the importance of simulation. This research can contribute to the continuous improvement of simulation programmes, thereby optimising patient care as a whole (WHO, 2018) and minimising the potential risk of hesitant or incorrect treatment by students.

Previous studies have demonstrated the positive impact of simulation training on students' knowledge, confidence and practical skills. AR simulations, such as those described here, enhance this effect by allowing active participation, accompanied by lecturer support for content clarification. Students actively participate using models and smartphones and receive immediate feedback on their actions. Detailed feedback at the end of the training reinforces skills and builds confidence. This interactive, hands-on approach to learning enables students to improve their skills. In addition, practical experience with materials and equipment significantly boosts confidence (Stoodley et al., 2020).

Students rated their confidence and practical skills as significantly improved. Although they also reported a significant increase in perceived theoretical knowledge, it was not as pronounced as in other categories. In summary, the results provide initial quantitative evidence of the effectiveness of AR simulation training. It can be concluded that AR simulation enables participants to enhance, supplement and refresh their technical knowledge. In particular, AR simulation training leads to improved confidence and the consolidation of practical skills (Malmström et al., 2017; Stoodley et al., 2020).

AR simulation was integrated into the curriculum, making student participation mandatory. While Wu et al. (2022) found lower acceptance with mandatory participation, our study received positive feedback and learning progress was perceived to have improved.

AR simulation provides students with a protected learning space which enables the connection between theoretical knowledge and practical application. In addition to the theory-practice transfer, self-directed and experiential learning is also supported (Miller et al., 2015; Lendahls and Oscarsson, 2017). These findings highlight the potential of AR simulation as a tool for holistic skills development in the healthcare sector, particularly in the training of future midwives.

Limitations

This study focused exclusively on the evaluation of the three AR simulation training courses presented here. The AR simulation was based on best practice standards for healthcare simulation, but did not fully address the relevant criteria. Similar tendencies can be seen in other studies in the field of simulation (Barlow et al., 2024). In addition, the study is based on a small sample due to the exploratory design. The generalisability of the findings to other midwifery programmes or educational settings may be limited. Future research involving different educational settings and possibly larger, more diverse samples would be helpful to confirm the replicability and applicability of the observed benefits of AR education. The relatively homogeneous sample was drawn from a single educational context, which may not be representative of wider student populations or learning environments.

This is an exploratory study, the results of which can only be used as initial indications and are not intended to be generalisable. A potential test-retest bias is inherent to the pre-post design. Further, it is important to note that the observed effects may not be exclusively due to AR simulation, as the fact that the students had a rehearsal could introduce a repetition effect. The lack of a control group could affect the interpretation of the results and limit the validity of the conclusions. Another limitation of this study is that the available data is based on student self-assessment and no objective measures, such as performance in practical examinations, were included in this publication. Future research should therefore include specific practical examinations which simulate stressful situations and emergencies in order to provide an objective assessment of skills. It is important to note that students' self-assessment may differ from the results of these examinations. In addition, using a longitudinal approach, data collection should be repeated at a later date to check whether the observed effects persist in the long term. The effects of AR simulation on emergency patient care need to be investigated in further studies. A further limitation is that an exploratory questionnaire was used which had not been tested for validity.

Conclusion

In summary, the results show that AR simulation has a positive and significant effect on midwifery students' self-assessment of knowledge, confidence and practical skills in emergency situations. The improvements observed are not only statistically significant, but also of practical relevance, indicating the effectiveness of simulation as a teaching method.

AR simulation training on a smartphone is suitable for promoting and consolidating procedural knowledge and practical skills in the context of complex situations. It can help to supplement or refresh specialist knowledge and, in particular, to teach confidence.

Further research is needed, especially in a qualitative and longitudinal context, to determine whether and how long the positive effect endures. The AR application (Heb@AR) is also available in English as an open educational resource and could be of interest to other European countries and beyond.

Funding

The AR simulation development was part of the externally funded project "Heb@AR - Augmented Reality supported learning for (student) midwives" and was funded by the German Federal Ministry of Education and Research (funding code: 16DHB3019) for the period from 01.09.2019 to 31.12.2022.

Ethical approval

The study received approval from the Ethics Committee of the Hochschule fuer Gesundheit Bochum (University of Applied Sciences).

CRediT authorship contribution statement

Kristina Vogel: Writing – original draft, Visualization, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Annette Bernloehr:** Writing – review & editing, Supervision, Project administration, Methodology, Funding acquisition, Formal analysis, Conceptualization. **Tabea Willmeroth:** Writing – review & editing, Data curation. **Jonas Blattgerste:** Writing – review & editing, Visualization, Software, Conceptualization. **Claudia Hellmers:** Writing – review & editing, Supervision. **Nicola H. Bauer:** Writing – review & editing, Supervision, Project administration, Methodology, Funding acquisition, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

This research was part of the Bachelor of Midwifery programme at the University of Applied Sciences Bochum, University of Applied Sciences and Arts Bielefeld and University of Cologne. The authors would like to acknowledge the students who participated in the study.

The authors would also like to express their sincere thanks to Prof Dr Thorsten Schäfer, Prof Dr Thies Pfeiffer, Dr Matthias Joswig, Martina Kunzendorf and Carmen Lewa, all of whom contributed either directly or indirectly to the study as part of the Heb@AR project.

This project is part of a PhD programme.

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