Enhancing Nurse Training: An AR-Based Training Prototype for Optimal Surgical Instrument Handling

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ABSTRACT

The safe and correct handling of surgical instruments is an essential aspect of training for nurses and medical professionals. However, this area of clinical education lacks sufficient support as traditional training methods can be resource-intensive, requiring significant supervisory involvement, and offer limited real-time feedback. With the increased capabilities of Augmented Reality (AR), an opportunity arises to enhance surgical instrument training by providing immersive, visual guidance on how to safely handle physical surgical instruments.

The aim of this dissertation is to explore how AR can be used as an interactive and self-paced training tool for scrub nurses by blending simulation with real-world practices and to assess how AR for training would compare to traditional training methods. To investigate these aims, a user study was conducted with nine medical professionals, to build an understanding of training challenges and objectives, and create design requirements for a proposed AR application. Based on these requirements a prototype AR system was then developed, capable of overlaying instructional visual cues onto surgical instruments. The focus is on the perspective of the scrub nurse handing surgical instruments to the surgeon.

Using surgical scissors and a scalpel, the system was developed to integrate object and hand tracking supported by visual design elements, developed in a Unity environment. The application provides nurses and medical students with visual guidance on the correct grasp and handover techniques for surgical instruments. This modular approach can be used as a blueprint that can be expanded to accommodate a wider range of surgical tools in future iterations. This dissertation demonstrates the potential of AR as a scalable, intuitive and accessible training tool for surgical instrument training.

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1 INTRODUCTION

Modern surgery as a branch of medicine has been studied and developed from as far back as the nineteenth century [15]. Although surgical techniques have evolved and improved dramatically with advancements in technology and understanding, for many surgeries that take place today, there is still a heavy reliance on the use of traditional surgical equipment such as scalpels or scissors.

Hospitals have strict guidelines surrounding the use of surgical equipment during an operation specifically with handling of instruments during surgical procedures [37]. As such, nurses are expected to be fully compliant with these guidelines with no exceptions. The aim of such guidelines is to ensure time efficiencies, prevent infections from percutaneous injuries and keep patients and doctors alike safe from injury [4, 15, 22, 36].

To reduce the risk of injury, staff training is needed for nurses to always ensure best practices and to reduce the risks through proper handling and disposal of sharp objects [36]. To facilitate this, currently there are methods of training which include certification programs, peer learning, clinical rotations and simulation training [28]. Simulation training is an evolving field and recently there has been a shift to using technology-based tools for simulation training. Simulation training has proven to be more effective in skill acquisition and in giving confidence to nurses by offering a safe environment to train in.

This dissertation works towards investigating and evaluating the mechanics of object handling and the trajectories in which objects are passed within the healthcare domain. To support this investigation, an augmented reality prototype was developed with the intention of enhancing the learning of proper surgical instrument handling. Augmented reality provides the ideal opportunity for introducing a practical-based learning approach by providing visual aids for handing and gripping surgical instruments, whilst giving the trainee an opportunity to practice these methods within a home, training laboratory or pre-surgical environment.

Augmented reality has been used in healthcare education fields before for the purpose of making healthcare education more accessible. The benefits of augmented reality in healthcare education include allowing students to practice independently, and at a pace of their choosing [38]. In addition, whilst object tracking is another common feature of many AR applications, this dissertation aims to further explore the specific procedures involved in passing objects. One of the main beneficiaries of this investigation, would be the healthcare training field where several factors determine how a medical instrument is passed from a nurse to a surgeon [13].

While current training approaches cover the identification and general function of surgical instruments, in some cases they do not employ an in-depth focus on the nuanced mechanics of grasping and passing instruments. If these critical actions are performed incorrectly, the consequences could lead to surgical delays or injuries. Existing AR applications in healthcare education have focused on visualisation tasks and procedural guidance, but there is limited attention given to the hand-object coordination skills required for collaborative tasks such as instrument handover. Many instruments differ from each other in how they are correctly gripped, oriented and presented to the surgeon by the scrub nurse. This is due to variations in the shape, function and the context in which the instrument is used. Consequently, training scrub nurses in learning these nuanced procedures requires more than general guidance. An AR-based solution can provide targeted, instrument-specific instructions for safe and efficient handling which reflects real-world passing techniques and positioning expectations.

This research aims to put more emphasis on specific hand-object interactions, by investigating the significance of AR in simulating safe and efficient instrument handling procedures. The objective for an AR-based tool in this regard would be to not only enhance the technical competence of nurses and trainees, but also to promote confidence and autonomy in real-world operating environments. This is followed by an analysis on the findings of the user study conducted with medical professionals, before a discussion on the possibilities of expanding this research into broader clinical training contexts. The medical professional participants for the user study consisted of five nurses, a theatre matron, a theatre educator, a general practitioner and a medical trainee. This dissertation also outlines the development of an AR prototype for training to handle surgical instruments based on feedback obtained from the user study.

2 RELATED LITERATURE WORK

Training to handle surgical instruments correctly requires the trainee to have a good technical understanding of the correct hand-object interaction techniques. These techniques vary between different surgical instruments, so the literature explored will expand upon the ergonomics and function of each specific surgical instrument used in open surgery. These techniques serve a purpose in ensuring the sterility of the instruments as well as protection for operating theatre staff and patients alike from injuries. Therefore, it is important to understand how these techniques prevent injuries by analysing different patterns of instrument passing. The section will also review current methods of training employed by scrub nurses from traditional learning methods to more recent simulation-based environments for training. The literature reviewed establishes how simulation based tools are supporting nurses and medical trainees in skill acquisition by adopting more technology-enhanced workflows for training. Furthermore, the section will consider what roles augmented reality (AR) can play within surgical training, highlighting the benefits of user-centred design and real-time visual guidance.

2.1 Types of Surgical Instruments (Open Surgery)

Firstly this subsection will explore the existing categories of surgical instruments in open surgery and their specific uses as seen in Figure 1. The reviewed literature is then accompanied by literature which expands upon the correct handling procedure employed by the scrub nurse when passing these instruments to the surgeon. The general categories to which this dissertation pays particular attention are as follows[6, 24]:

- **Cutting and Dissecting Instruments**
  - Scalpels
  - Surgical Scissors
- **Grasp and Hold Instruments**
  - Forceps
- **Clamp Instruments**
  - Clamps
- **Suture Instruments**
  - Needle Holders

Figure 1: General instruments used in open surgery from left to right: Clamps, Needle Holder, Surgical Scissors, Scalpel.

The scalpel is an instrument that consists of a blade and a handle. Its primary purpose is to make surgical incisions by manually cutting through human tissue using the blade end of the instrument [24]. When passing such sharp instruments, it is important to maintain sterilisation of the instruments and avoid injury to staff, therefore the scalpel is grasped from the handle above so that the blade is pointing backwards and away from the surgeon. The surgeon may choose to grip the blade from above or the surgeon may grasp the scalpel like a pen as if it is being used to write [18].

Surgical scissors are instruments used to cut through human tissue. The design of these instruments can vary depending on the depth of the body they are used in. The handle section of the scissors can either be ring-shaped for inserting the thumb and index finger, or it can be spring loaded. The two blades are connected by a screw to allow for opening and closing the instruments. The blades can be either rounded at the end or both pointed. Meanwhile the working part of the pair of scissors can be straight, bent or angled depending on the application. When presenting the scissors to the surgeon, the scrub nurse must grasp the instrument at the cutting blades end. This means that the rings of the handle are readily available for the surgeon to access. Depending on the curvature of the blades, if the curvature is above the index finger, the scissors will point downwards towards the tissue. If the curvature is over the thumb, the tip of the scissor will point upwards [18].

Forceps, also known as tweezers, have the primary purpose of grasping the tissue to be cut, prepared or sutured. They are used by the surgeon in one hand whilst the surgeon is holding a needle or scissors in the other hand. The tweezers themselves consist of the "jaws" which grasp human tissue when pressure is exerted, and the handle which is gripped by the surgeon. Forceps can either be straight where the handle seamlessly joins the jaws in a parallel alignment, or they can be angle-bent which features a gentle curve between the jaws and the handle. Scrub nurses will grasp the straight forceps at the bottom of the working ends and are placed upright in surgeon's hand. The instrument will usually be presented to the surgeon's left hand as the other hand is needed for the addition of scissors or needle holders. For angle-bent forceps on the other hand, the instrument is presented in a way such that the upper angle points downwards towards the patient.

Clamps are instruments which on the surface have a similar shape to surgical scissors with rings on the handle side of the instrument, but the "jaw" profile of the instrument differs on intended use for short-grip as well as long-grip. Their primary purpose is to grip tissue or material. They are available in different shape variations which include but are not limited to: straight, angled, curved or bayonet-shaped. For handling these instruments the surgeon must be able to reach into rings of the handle, so the scrub nurse should grip the instrument from the working part when presenting. For straight clamps, these should be presented to the surgeon so that the working end points upwards. Angled clamps are presented such that the upper angle points downwards towards the patient. Curved clamps are presented with the angle pointing downwards. The positioning of the surgeon in relation to the scrub nurse is also a determining factor for presentation. If the surgeon is facing the nurse, the clamp is grasped from the working part of the instrument while the bend wraps around the thumb. In contrast, if the surgeon is next to the nurse, the bend is formed around the index finger. In this context the "bend" refers to the curvature or angle in the working part of the clamp [18].

A needle holder is similar in appearance to a clamp as it typically has a handle and a short "jaw". The jaw often has a texture or grooved surface and the instrument is designed to hold and guide needles precisely during suturing. Suturing is the process of closing open wounds by stitching tissue together [20] . For presenting this instrument, the scrub nurse will grasp the needle holder at the working end and is presented upright in the surgeon's hand to again ensure that the surgeon is easily able to grasp the instrument from the rings of the instrument [18].

2.2 Patterns of Passing

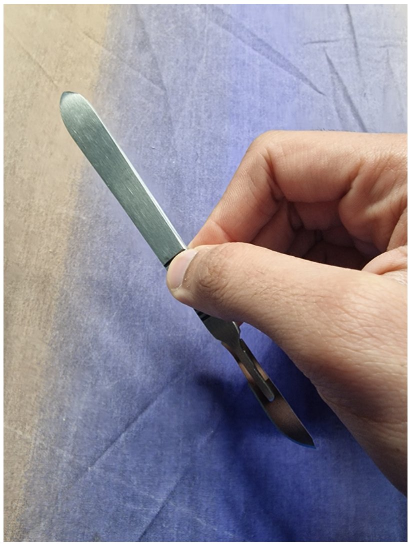
Scrub nurses are responsible for preparing and passing instruments to the surgeon in a safe and efficient manner. The relationship between the scrub nurse and the surgeon is such that the scrub nurse must "anticipate the needs of the surgeons" as well as have surgical equipment ready to be passed to the surgeon [29].

Existing guidelines emphasise the need for handling sharp instruments (e.g. scalpel blades, suture needles) with extreme care to prevent accidental cuts or injuries [21]. Sharps injuries account for a significant proportion of operating theatre incidents, which highlights the importance of proper passing technique. In order to reduce the risk of sharps-related injuries, some practices recommend using a "hands-free" passing technique which designates a *neutral zone* on the instrument being handled. This approach avoids the simultaneous handling of sharp edges by two people [3]. The effectiveness of this approach is evidenced in studies which reported that the use of neutral zones, can reduce sharps injuries by 35% to 59% [34, 35]. This approach could be adopted within an AR based application which designates "safe" and "unsafe" zones for handling a sharp instrument.

In terms of general guidelines for nurses when it comes to handling these instruments, the scrub nurse must grasp each instrument at the working part so that the surgeon can grasp the instrument and immediately start to use it without adjusting the position or angle of their hand as showcased in Figure 2. The working part refers to the functional part of the instrument that will perform the intended action. For surgical scissors for example, this could refer to the blades of the scissors. Presentation is also a key aspect of passing objects where the type of instrument being handed influences the angle of presentation. Scrub nurses may also work with two hands where one hand is used for presenting the instrument to the surgeon while the other hand is used to receive the used instrument from the surgeon in a smooth workflow for a smooth transition [19].

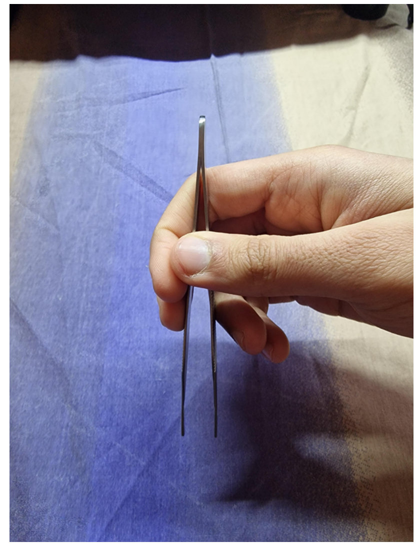
Studies have proven that the smoothness of an object transfer is dependent on the relative positioning and alignment of the scrub nurse. Korkiakangas et al. (2014) conducted video analysis of the passing of instruments during surgical operations [16]. This study observed that one of the main factors that affected the speed of object transfer was the alignment of the scrub nurse, relative to the surgeon. When scrub nurses were stood close to the surgeon, instrument handovers were seamless and took less than one second. In cases where the nurse stood further away from the surgeon exchanges of instruments were slower taking more than one second. Consequently, the distance of the nurse relative to the surgeon is an important consideration that was taken into account for the AR prototype.

To summarise, scrub nurses must grasp safe handling to prevent injuries and efficient passing to avoid delays, when using various instruments. By following standard guidelines and safe practices such as neutral sharp instrument zones and observing an appropriate distance to the surgeon, scrub nurses are able to effectively assist the surgeon during a surgery.



(a) Scalpel

(b) Surgical Scissors



(c) Forceps

(d) Needle Holder

(e) Clamps

Figure 2: Figure showing how each instrument is presented by the scrub nurse

2.3 Methods of Training for Scrub Nurses

Traditionally scrub nurses would learn by observing a senior nurse or surgeon within the operating theatre before double scrubbing, where a more experienced staff works with a less experienced nurse. The double scrubbing approach, stands to be "an integral part of nurse education" for contextual learning with recognising surgical instruments and developing an understanding of their related functions [30]. The study highlighted that there is a need for having a "basic foundation of new knowledge to learn technical scrub skills". Within this study by Radford et al. (2018), scrub nurses remarked several comments on this double scrubbing approach where some novice nurses were unsure about how their performance in procedures and would seek reassurance. Additionally, some had also remarked that there was a lack of structure within their training program. As a result of these issues, novice scrub nurses have frequently reported high levels of stress and anxiety when first learning to handle instruments during surgeries [8]. Our prototype solution aims to support scrub nurses in training by providing a standardised method of learning through tutorials, where the visual aids are consistent in appearance across all instruments.

Current methods of training show an increased trend towards simulation-based learning as it has been widely adopted now in nursing and medical education [2]. The systematic review by Alharbi et al. (2024) evaluated the impact of this learning approach by analysing computer-based simulation as well as high-fidelity simulation. An example of a high-fidelity simulation could be a training laboratory designed specifically to simulate a general ward setting. The review compares the performance of high-fidelity groups or computer-based learning groups exclusively in addition to a mixed approach of using both. The mixed approach was found to be more effective in improving the skill of nurses in the short term. An AR-application in this regard could utilise the benefit of accessibility where it can be used in a clinical setting as well as use advanced computational abilities to simulate the training of using surgical instruments. The main benefit of having a simulation based environment, is offering a safe environment where nurses might make mistakes but can repeat procedures. This means that nurses do not have to carry the consequences of making errors during a live operation [8].

Additionally, researchers have explored virtual reality (VR) as a platform used to host scrub nurse education. As an example, Edwards et al. (2021) introduced an immersive virtual reality curriculum for orthopaedic scrub nurses, where a user is guided to perform instrument selection, assembly and passing in a VR operating room over multiple sessions. The study reported that nurses who trained in VR, complete a procedure on average 50% quicker as compared to their pre-training baseline (reducing from approximately 55 minutes to 29 minutes on average) [8]. The authors note that repeated use of the VR environment led to increased efficiency and technical understanding in complex surgical environments. Although there are drawbacks with such technologies such as temporary dizziness, as reported by Edwards et al. (2021), the acquisition of complex skills are transferable to the real world from the simulation; this is true provided that the simulation accurately replicates real-world procedures for training.

Another such interactive system was developed by Glaser et al. (2016) through the use of computers, monitors, touchscreen and an interactive table with scrub nurses being the intended user in mind [10]. This training system proved effective in helping scrub nurses familiarise themselves with surgical instruments. An AR approach could expand upon this by providing visual cues on handling the correct parts of an instrument as well as influencing correct presentation techniques, in addition to providing visual cues for identifying instruments and their constituent parts correctly.

There is an emerging technology in the form of robotic scrub nurses with the objective of addressing a shortage of scrub nurses within the operating theatre [32]. One of the aims with these robotic scrub nurses, is to ease the workload faced by operating theatre nurses by focusing on the primary role of instrument handover. In a traditional surgical setting, the scrub nurse would act as "mind-readers" and establish verbal communication with the surgeon to anticipate the correct instrument to handover. In contrast, robotic nurses typically rely on visual gestures elicited by the surgeon to indicate the desired instrument of handover [14]. However, there are various challenges with robotic nurses including precision, timing and communication with the handover procedure [32].

In short, training scrub nurses has traditionally relied on methods of observational learning and double scrubbing with experienced staff. While these methods are effective for contextual learning, they often lack structure and in some cases do not provide a stress-free environment for nurses to practise in. This can lead to anxiety and lack of confidence, particularly amongst novice nurses. A recent shift towards simulation-based education, has mitigated these problems by offering safe environments for practice. Additionally with the use of technologies such as high-fidelity simulations and virtual reality, these methods have been effective in increasing technical proficiency and efficiency in surgical settings. Augmented reality serves as promising avenue to explore, as it combines accessibility with structured visual guidance, to support learning to handle surgical instruments.

2.4 Role of Augmented Reality in Hand-Object Interaction for Surgical Training

Augmented reality techniques allow for systems that are capable of rendering 3D virtual objects in real time as an overlay in the real world. These techniques bring the benefit of task visualisation when it comes to hand-object interaction use cases. In the medical field for example, a training tool was developed by Wijdenes et al. (2018) with the objective of creating a standardised training tool for medical students to practise Central Venous Catheterization [38]. Wijdenes et al. (2018) highlighted a need to design a system that is self-directed, and investigated using AR as a technology for such a system. The tool showcased an AR rendering of virtual hands and a catheter, accompanied by instructions on inserting the catheter into a dummy model. As part of the future learnings recommended from this paper, the "competency development of medical learner trained with the AR application, relative to the current learning standard should be compared". The research undergone in this dissertation intends to evaluate the competency in handling surgical instruments with an AR application and compare this to traditional learning methods.

Furthermore, with the benefits of object detection combined with AR, users can gain better spatial understanding of where objects are within a field of view through visual markers and indicators of where objects are placed, allowing for safer interaction with dangerous objects as demonstrated by Lee et al. (2024) [17]. These benefits however could also be realised in the domain of training with surgical instruments, as safety is a paramount concern where the advantages of learning safe instrument interaction could be realised with increased engagement and immersion from utilising an AR tool.

Moreover, AR plays a significant role in real-time feedback and corrections when it comes to object interaction. In the application of using surgical instruments, this is vital to ensure efficiency and safety in the handing of objects from a scrub nurse to a surgeon. This can be achieved by displaying visual cues in the AR system. A notable example is an object interaction AR system developed by Sharma et al. (2024) to translate gestures into actions through the different phases of physical object interaction [33]. Their system demonstrated how the inclusion of micro-interactions embedded within natural hand movements could support real-time input without disrupting task flow. This paper highlighted how participants responded positively to the feedback mechanisms, suggesting that the incorporation of feedback interfaces can translate into a seamless rather than obstructive user experience. By including similar mechanisms for feedback in surgical training, scrub nurses can receive immediate guidance and corrections when presenting instruments.

A fundamental element of a functional AR application is the user interface, and therefore several design considerations must be taken into account to allow a user to respond effectively to visual cues and ensure an optimal user experience [5, 17, 33, 38]. Within any design interface, if an interface is not designed appropriately, this "can overwhelm the user and complicate information access" [5]. In order to create an effective and meaningful design for an AR-based application, a user-centred design approach must be taken. Albrecht-Gansohr et al. (2023) explores several methods that have been adopted for developing an AR application with nurses [1]. One such method employed in these workshops was creating a persona story where the designers constructed a user story enabling the nurses to contribute ideas more effectively by considering the context. Another method was conducting co-design workshops with nurses. This is also is known as participatory design where the stakeholders are involved actively in the design process [11, 25]. These ideas were taken into account for the user study, where the methodology is expanded upon in Section 3.1.3.

There are more examples of AR healthcare applications, that have been developed with the close involvement of end-users (such as nurses, surgeons and educators) in order to ensure that the application is intuitive and addresses real needs. Nelson et al. (2021) developed an AR triage training tool for emergency responders, which was created through iterative design with expert interviews, usability testing and revisions based on user feedback [26]. By incorporating the input of end-users, the designers were able to prioritise features that aided the workflow of the task and eliminated features that could distract the user in a critical scenario. Similarly, virtual reality tools have been developed for the education of scrub nurses, in which the use of user evaluations has been crucial to verifying the correct development approach as presented by Nguyen et al. (2024) [27]. The developers of this neurosurgical scrub nurse VR simulation collected qualitative feedback from participating nurses, who reported high acceptability and positive opinions on the realism of the simulation.

With AR user interface designs, the user experience is also impacted by the choice of object augmentations against affordance augmentations. Object augmentation is the traditional method of highlighting objects as a whole whilst affordance augmentation focuses more on the usability of objects by highlighting an object's functional parts. For example, as demonstrated by Lee et al. (2024), common visual techniques for affordance augmentation designs could include different colours for outlining safe parts of an object to handle or hazardous parts to avoid touching using a traffic light system [17]. Furthermore arrows could also be used instead as an indicator for assisting the user in correct handling methods. This idea was applied to the training tool, as surgical instruments are an obvious fit affordance augmentation. This is because the shape of surgical instruments can be easily divided into the handle and the working part, where the UI would focus on assisting nurses on grasping the correct working part of the instruments by using colours or other visual cues.

In summary. augmented reality has shown considerable promise in enhancing hand-object interaction training by providing 3D visual overlays that guide users in complex tasks. This can be further supported by real-time feedback, affordance augmentation and correction mechanisms which can be applied in training scenarios to allow scrub nurses to improve handling techniques dynamically. However, it must be noted that AR applications rely on effective user-centred interface design to a great extent. A poorly designed interface could risk overwhelming users and reduce performance in tasks. Existing studies support the use of user-centred design approaches which actively involve the end-user in the design and development of AR and VR applications.

3 METHODS

The first part of this section outlines the methodology used for the user study which informed the design requirements for developing the AR prototype. The first part will outline the methods used to carry out the user study in the form of an interview with medical professionals, which included surveys and a informal discussion with the participants. In the second part of this section, the focus will be on the technical development of the application prototype. This includes the tools and platforms used to develop the design and tracking elements of the application, as well as the functional workflow of the prototype and how this supports the grasp and handover phases of surgical instrument use.

3.1 User Study Interviews

In this section, the methods used to carry out the user study with medical professionals will be discussed.

3.1.1 Participants. The user study was conducted with nine medical professionals, including five nurses. There were two main objectives of this user study:

- To explore the value of AR for surgical training.
- To understand the challenges, preferences and expectations around instrument handling and training.
- To evaluate and collect feedback on mock-up designs for the AR application.

3.1.2 Sampling Strategy. Participants were recruited based on the criteria that they were above 18 years of age, could speak English proficiently and were fully qualified medical professionals, with training or experience in the use of surgical instruments. This approach ensured that the requirements for the system, were relevant and catered to the intended end users being nurses or medical trainees.

Based on the stated reasons above, a non-probabilistic convenience and snowballing sampling approach was applied where the participants were specifically selected based on the above stated criteria. The user study was therefore advertised by posting a recruitment poster on various nurses group platforms on LinkedIn, which specified the purpose of the project, the inclusion criteria, expectations of the participant and the rights of the participant. Each participant then reached out through email to confirm interest in participating, and once recruited was asked to share the recruitment poster and recruit as many more participants as possible within their respective social groups, as a form of snowball sampling.

3.1.3 Procedure. The user study interviews with each participant, took place over Microsoft Teams. The participants were guided throughout the interview through explanations from the researcher in addition to a Microsoft PowerPoint presentation that was shared throughout the interview. The procedure of the interview was as follows:

(1) Participants were initially given an introduction to the project background and rationale of the project.
(2) Participants were asked to review the participant information sheet and sign the consent form.
(3) They then completed a short survey covering their training background, familiarity with surgical instruments, and their views on the usefulness of AR in a medical training context.
(4) Subsequently participants were then shown videos demonstrating how AR is currently being used in commercial and healthcare applications.
(5) Participants were shown mock-up augmentation designs for two main phases of the application:
    - How to help nurses understand the correct instrument grip.
    - How to help nurses understand the correct passing procedure of instruments to the surgeon.
(6) The researcher constructed a user story where the participants were asked to employ the mindset of a new medical trainee or nurse beginning to learn surgical instruments. Afterwards they were asked to reflect upon the functionality and the usefulness of the designs by engaging in an informal discussion with the researcher. Feedback was transcribed for qualitative analysis using the Microsoft Teams AI transcribe feature.
(7) Finally, participants completed a final survey to capture their preferences for which AR device they would prefere to use and the ideal combination of augmentation designs for the two main phases of the application.

3.2 Application Development

Following the user study, the main application was developed based on the feedback of designs from the users. This subsection will cover the main tools, techniques and technologies used in the process of designing and creating the application.

The objective of the application is to allow new nurses or medical students alike to access training tutorials for handling specific surgical instruments. The tutorials can be performed and repeated whenever needed in a training lab or home setting. The only requirements for this application, include having a supported smartphone or AR device such as a Microsoft HoloLens 2, in addition to a physical practice surgical instrument kit. Separate tutorials were developed for two instruments - the scalpel and the surgical scissors. Please refer to the GitHub page which contains a video tutorial, the source code for the application as well as a README guide which explains how to use the application [9].

3.2.1 Technologies Used.

Unity Platform and Blender. The Unity platform was used to develop the main application which includes the design for the augmentations, as well as the code logic to apply the specific augmentations at each stage.

Blender was used for modelling, rigging, and scaling the 3D models of the surgical instruments. This involved scaling the surgical instrument models for the surgical scissors and scalpel to match the exact size of the real instruments used for the tutorial. In addition, the 3D hand models were rigged to into the desired pose and position for use in the application [23]. The hand models were then exported to Unity.

Vuforia Model Targets. For object tracking of the surgical instruments, 3D models of a scalpel and surgical scissors was used and the scale of the 3D models was adjusted to replicate the exact measurements of the real surgical instruments to the nearest decimal[31]. Following this, the 3D instrument models were uploaded to the Vuforia Engine Model Target Generator. This works by generating an object recognition and tracking model of the uploaded 3D instrument model, that can be recognised from any angle within a 360 degree viewing space when viewed through an AR camera. The object recognition and tracking model works by estimating the object's position and orientation relative to the camera. This marker-based tracking approach allows for AR content to be overlaid directly on the tracked instrument in real time, as the model uses visual markers from the uploaded 3D instrument model for identification of the instrument in the real-world environment.

MediaPipe Hand Landmark Tracking. Hand tracking was also integrated by using the MediaPipe Hand Landmarks Unity Plugin integrated to track the position of the user's hand with reference to the 3D hand overlaid on top of the augmented instrument showing the ideal grasp position [12]. The landmarks in question track the bone joints of a single hand in frame at a time [7]. Hand tracking in the application, takes the live video feed from the AR camera and uses the machine learning model for inferring when a hand is detected. Upon detection, the system updates the logic for displaying and hiding different augmentations as explained in the subsection below.

3.2.2 Application Workflow. For a detailed video walk-through of the application, which showcases a typical use case for both the scalpel and the surgical scissors tutorials, please refer to the attached video material which can also be found on the GitHub repository page [9].

Grasp Phase.

(1) Augmentations of green (grasp) and red (danger) grip zones first appear on the physical surgical instrument once the instrument has been detected.
(2) A 3D virtual hand model will also appear, demonstrating the proper grasp pose for instrument handover with respect to the instrument in question being handled.
(3) Real-time hand tracking is performed using the MediaPipe Hands plugin for tracking when the user's hand aligns with the position of the 3D virtual hand. Once the user's hand is detected, the virtual hand will change colour from blue to green.

Handover Phase.

(1) The augmentation on the instrument changes to hide the grip zones and subsequently displays an arrow indicator passing straight through the instrument. This indicator turns green when the specific orientation of the instrument is correct and red when incorrect.
(2) The user then taps the screen to place a virtual 3D surgeon's hand mid-air. The 3D hand is set in a position emulating a surgeon's pose with respect to the instrument being handled. The 3D hand is placed in the real world space by the user in the desired location.
(3) A path trajectory line is displayed from the user's hand to the virtual surgeon's hand guiding the instrument through the correct trajectory.

4 RESULTS

In this section, the findings from the results gathered in the user study interview are summarised. This contains quantitative analysis from the surveys and qualitative insights from transcripts of each interview. The initial survey gives us an understanding into the training background and challenges of each participant, as well as general attitudes toward the usefulness of AR for surgical instrument training. The following subsections then introduce the proposed mock-up designs presented to the participants, which outline how the application could visually support the grasp and handover phases. The qualitative analysis covers participant feedback on all design concepts, in addition to the views of the participants on the potential benefits, usability and design intuitiveness of the AR system. Finally, the results of the second survey asking participants to indicate their preferences on design concepts are presented, which justifies the approaches taken for the development of the application.

4.1 Participant Background and Usefulness of AR

The initial survey was completed by all nine medical professional participants, with five participants out of nine being nurses. Other participants included a theatre matron, theatre educator, general practitioner and a medical trainee. Responses revealed that 6 out of 9 participants had experience in their respective fields of over 10 years, and also that 5 participants were involved in surgical procedures daily.

Training with surgical instruments was mainly acquired through on-the-job mentoring as indicated by eight of the participants, whilst formal classroom learning was another common form of learning as reported by four participants. A smaller proportion also reported self-directed methods of learning through online courses and video guides, whilst only one participant had undergone simulation based learning. Common resources that were used for surgical training ranged from hands-on practice in training labs, printed manuals, mentorship (shadowing) experiences and a smaller proportion using self-directed learning resources such as online courses and video guides.

When quizzed on primary challenges faced during training to handle surgical instrument, the most common challenge identified was difficulty in remembering instrument names and functions as reported by eight of the participants. Other commonly reported challenges included dealing with stress in high-pressure environments when training as well as insufficient hands-on practice opportunities. Conversely, when the participants were asked to evaluate the effectiveness of current training methods on a Likert scale ranging from **"Very effective"** to **"Very ineffective"**, all participants did report that current methods are **"Somewhat effective"**. This would suggest satisfaction with established training methods. However it is clear that participants feel there is still room for improvement related to solving previously mentioned challenges in order to obtain complete satisfaction.

On the subject of technology-based training tools such as e-learning modules or AR/VR simulators, survey results showed that the use of these tools was limited. Only one participant had occasional experience with these tools, while the rest had never used them. In contrast, participants showed strong enthusiasm to the idea of using AR technologies in surgical training, as all participants agreed that AR could be highly useful. This is especially true for the following list which illustrates all areas that participants acknowledged could benefit from the introduction of AR, as well as the percentages of all participants who indicated these options:

- Understanding instrument functions (100%)
- Practising handling techniques (100%)
- Understanding correct passing procedures (89%)
- Recognising instruments by name/shape (78%)
- Preparing for rare or complex procedures (56%)

In response to a question on potential scenarios that they would use AR training in, eight of the nine participants preferred using it in structured environments such as a pre-srugery setting or in a training lab. Four participants were also open to using AR tools at home for self-guided practice.

Finally participants were asked to add any further comments related to training, surgical instruments or the implication of AR as participants further emphasised enthusiasm to the introduction of AR in surgical training. Several participants noted that AR could be especially beneficial during the early training phase for nurses or additionally for helping experienced staff learn unfamiliar instruments. One participant discussed the potential usefulness of AR for individuals with specific learning needs. While there was recognition that AR could represent an innovative step forward for surgical training, another participant specified that AR may not fully replicate the practical feel and handling of physical instruments, suggesting that the integration of physical instruments remains essential for a realistic training experience.

4.2 Proposed System Design Options

Following the survey, participants were shown video demonstrations on the applications and potential of AR. They were then shown options for different design mock-ups of the application in the form of animations.

4.2.1 Grasp Phase Design Options. Participants were presented with three different design options for the grasp phase. They were presented with examples for all instruments including scalpel, surgical scissors, clamps, forceps and needle holder. The design options presented are not accurate to how they would be grasped in practice, but they illustrate the principle design concepts that the application intended to achieve. All instruments were presented to allow the participants to understand how the designs would generalise to each instrument. An example of the options for the grasp phase can be seen in Figure 3.

(1) **Grip Zones**
Green and red zones are overlaid directly onto the surgical instrument to indicate safe (green) and unsafe (red) grasp areas.
(2) **Virtual 3D Hand**
A virtual 3D hand model is overlaid on top of the instrument, demonstrating the correct grasp technique by positioning the hand in the proper orientation over the instrument.
(3) **Arrow Indicators for Finger Placement**
Colour coded arrows are overlaid on top of the instrument, indicating which fingers (e.g., thumb, index) should be positioned on specific parts of the instrument for correct handling.

4.2.2 Handover Phase Design Options. Participants were then shown three different design options for the handover phase. Again they were presented with examples of all surgical instruments to help better understand the generalisability of the design options to all surgical instruments. An example of the handover phase options can be seen in Figure 4.

(1) **Presence of the Surgeon's hand**
A virtual 3D model of a surgeon's hand displayed at the target location to guide where the instrument should be passed.
(2) **Orientation Arrows**
Orientation arrows displayed over the instrument, changing colour (green or red) depending on the angle at which the instrument is held for handover.
(3) **Path Trajectory Feedback**
A dynamic trajectory arrow drawn from the user's hand holding the instrument towards the surgeon's hand position, guiding the correct path for handover.

4.3 Design Feedback

After presenting the individual design options for both the grasp and handover phases, each participant was asked to evaluate the feasibility of each option, in the context of a new medical student or training nurse beginning to use surgical instruments. They were encouraged to discuss their impressions of each design and subsequently completed a short survey to indicate their preferred combination of options for each phase. This allowed for the researcher to gather qualitative insights from open-ended feedback and quantitative data on preferences for what visual design elements should be used in the training application. This subsection presents a summary of the informal feedback for the presented options, derived from participant transcripts.

Participant Feedback on Grasp Phase Designs. Participants indicated that the AR overlays during the grasp phase would be greatly beneficial, especially for new trainees learning surgical instrument handling for the first time. Differentiating between the safe (green) grip zones and the unsafe (red) grip zones of the instrument was noted as being intuitive and easy to understand. One participant described the grip zone overlays as "really clear for someone who's never picked up an instrument before" (Participant 4).

With regards to the presence of a virtual 3D hand on top of the instrument, this was perceived as a valuable addition, as it offered a natural reference for a nurse to position their fingers and hand. Another participant also stated, "I like that the hand is over it because you can see how your fingers are meant to be" (Participant 3). Having grip zones as well as the 3D hand overlaid on top of the instrument, was viewed as an effective combination of features for the grip phase of the proposed system.

Having the additional colour coded arrows for exact finger placement was appreciated for giving more explicit instruction to the user, however the general consensus was that this design option could be confusing as one participant stated, "It could be confusing if there's too much on screen at once, especially for beginners" (Participant 5). Overall participants agreed that AR-based guidance in the grasp phase would accelerate early learning and build safer handling practices from the start.

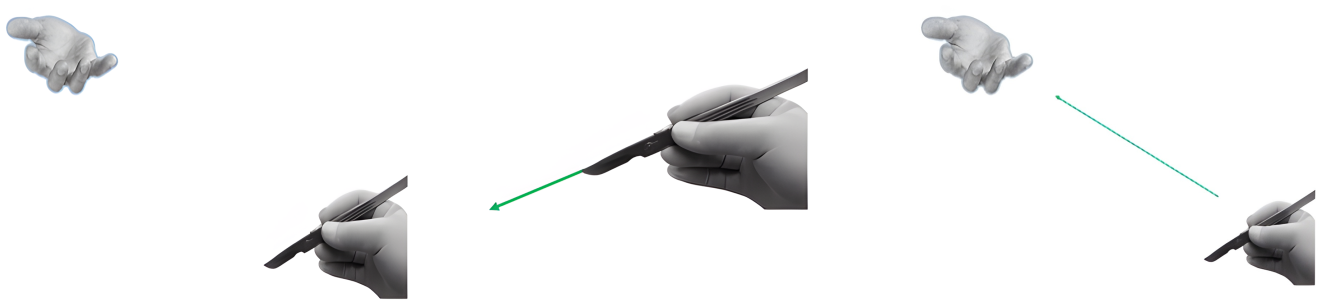
Participant Feedback on Handover Phase Designs. Feedback on the handover phase designs was also very positive. Participants valued the presence of a virtual surgeon's hand as a realistic target to practise handing the instrument over to the surgeon, as noted by a participant who describes that "it feels natural to pass to a hand" (Participant 7).

The overlaid arrows that changed colour based on the vertical orientation of the instrument was seen as an effective and immediate form of feedback. As one participant remarked that "Seeing it [the arrow] turn green straight away would tell you without needing anyone to correct you" (Participant 9).

Displaying a virtual trajectory path in the form of a dynamic arrow line guiding movement was also seen as a beneficial aid for visualising the correct path of motion in directing the hand holding the instrument to the surgeon's hand. An important consideration was pointed out by a participant, that in live surgeries the surgeon's position is not static in the operating theatre. In some cases surgeon could be standing on a pedestal to reach a certain height, and the surgeon's dynamic movements should be reflected in the application as participant 4 pointed out, "In real life the surgeon might move or change position, so ideally the target hand should move too."

(a) Option 1: Grip Zones (b) Option 2: Virtual Hand (c) Option 3: Arrow Indicators

Figure 3: Surgical Scissors Design Options Presented for the Grasp Phase



(a) Option 1: Presence of Surgeon's Hand (b) Option 2: Orientation Feedback (c) Option 3: Path Trajectory Feedback

Figure 4: Scalpel Design Options Presented for the Handover Phase

For the most part, participants agreed that a combination of all three visual elements including the virtual surgeon's hand, the orientation arrows and the trajectory line, would provide the best simulation of the instrument handover phase.

Overall Impressions of the AR Application Idea. To a large extent, participants consistently expressed positive attitudes toward the overall concept and design of the AR training application. They appreciated the clarity and simplicity of the visual elements, which allows tasks to be understood quickly without the need for detailed instructions.

Participants pointed out that the application would be a convenient tool for novices in particular, but also for experienced medical professionals. "It would be really good for new nurses during their training phase, or even experienced ones learning new instruments" (Participant 3). The AR interface was seen as enabling independence to learners, with one participant stating that "It frees up time because they can practise the basics before needing supervision" (Participant 5). In general, the designs were perceived to be innovative, useful and relevant to the growing demands of surgical training as well as the advanced technological capabilities available to us through Augmented Reality.

Identified Areas of Improvement. Participants suggested several key areas for enhancement:

- **Physical Feedback:**
  While several participants stated that the proposed AR system offered excellent visual guidance, there was still a need for tactile realism. As participant 9 mentions that "You still won't get the actual feel of the weight or balance of the instrument." Therefore incorporating the use of physical instruments is a must, whether for surgical practice or training at home or in a lab.
- **Collaborative Interaction:**
  Participant 7 suggested that the realism could be further enhanced by enabling both the trainee and the surgeon to wear AR headsets for use in a surgical environment. They suggested that this could be supported by a mechanism that allows the surgeon to see the same augmentations that are being experienced by the scrub nurse handling the instrument.
- **Customization:**
  Another proposition from the participants was that users should be able to adjust the level of visual feedback displayed by the system depending on their learning level. "Maybe let people choose - if they're new, they can have more help, but if they're experienced, they can turn it off" (Participant 4).
- **Sterility and Clinical Use:** One participant suggested the possibility of integrating the AR functionality directly into

a sterilised splash visor or surgical goggles. Such an implementation would allow for AR guidance to be used in real surgical environments without compromising sterility. This highlights the potential for AR to support real-time clinical practice as well as training.

4.4 Quantitative Analysis on Design Preferences

At the conclusion of each user study, participants were asked to complete a short final survey to indicate their preferences regarding the hardware of choice to host the AR application, as well as their preferred design features for the grasp and handover phases.

Preferred AR Device. Firstly, participants were asked to rank their preferred AR device of use from *"Most preferred"* to *"Least preferred"*. Participants were presented with the following three options:

- **Smart Glasses:**
  Wearable devices in the form of glasses that allow for hands-free augmented overlays in a lightweight form factor.
- **AR Headsets:**
  Larger and more immersive head-mounted displays (such as the Microsoft HoloLens) offering more robust spatial mapping and interaction, but with added weight and bulk.
- **Smartphones or Tablets:**
  Handheld devices that display augmentations on top of the live video camera feed on screen, though requiring the user to manually hold the device during use.

A majority of the participants favoured **smart glasses** over traditional AR headsets or handheld devices as seen in Figure 5, with the following survey metrics supporting this conclusion:

- 4 participants selected smart glasses as their first and four selected the glasses as their second choice, totalling 8 highly ranked selections for smart glasses.
- 5 participants selected AR headset as their first choice but only two selected it as their second choice, totalling 7 highly ranked selections for AR headset.
- A majority of the participants (6) ranked handheld devices as their third choice, making it the least popular.

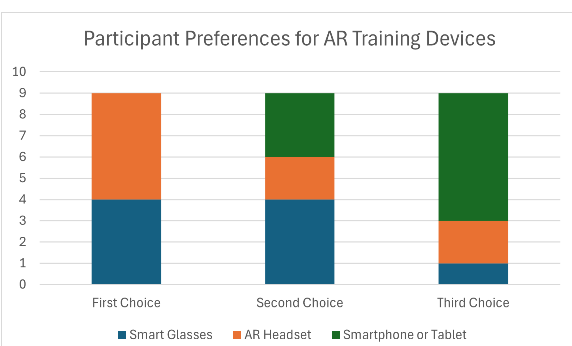


Figure 5: Results showing the ranking of participants' choices among the three AR device options.

AR headsets were seen as potentially too bulky for comfortable long-term training sessions. Smartphones and tablets were ranked lowest overall, due to the requirement of having to manually hold the device which would not be suitable for interactive surgical instrument training.

Preferred Options for Grasp Phase. Participants selected their preferred design options to help a nurse understand the correct grasp procedure for a particular instrument. (Figure 6)

- **Grip Zone Highlighting** was the most favoured option, selected by 8 out of the 9 participants, accounting for *62%* of all votes.
- **Virtual 3D Hand Overlay** was the second most popular option as it was selected by four participants, accounting for *31%* of all votes
- **Arrow Indicators for Finger Placement** as an option by one participant, accounting for *8%* of all votes. This is likely due to concerns expressed by other participants about potential confusion and overwhelming complexity for new users stemming from this design.

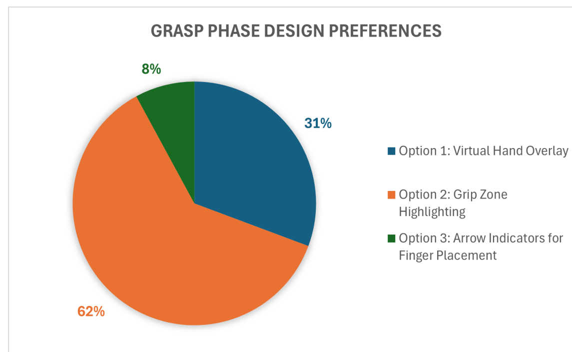


Figure 6: Results showing the proportion of participants' choices among the three grasp design options.

These results indicated that a combination of having grip zone overlays and a virtual 3D hand showing correct placement, was the ideal design approach for the application prototype. The inclusion of the arrow indicators would likely have created an unintuitive user experience, therefore it was not included in the final application prototype.

Preferred Options for Handover Phase. Participants also selected their preferred design options for aiding a nurse in understanding the correct handover procedure from the nurse's hand holding the instrument, to the surgeon's hand. (Figure 7)

- **Orientation Feedback (Colour-Changing Arrows)** was the most popular design option, selected by 7 participants, accounting for *44%* of all votes.
- **Presence of Virtual Surgeon's Hand** as a design option was chosen by 5 of the participants, accounting for *31%* of all votes.
- **Path Trajectory Feedback** was selected by 4 participants, accounting for *25%* of all votes.

For the handover phase, all three design options were incorporated into the application prototype as participants did not state concerns with the feasibility of the aforementioned options.

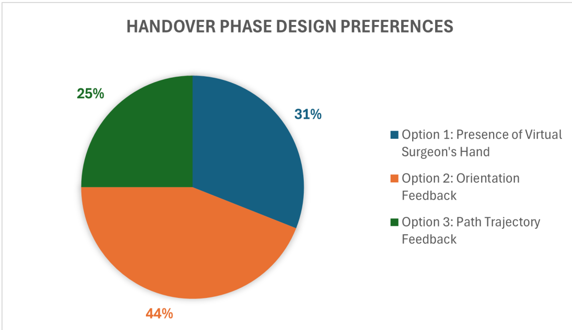


Figure 7: Results showing the proportion of participants' choices among the three handover design options.

5 CONCLUSION

The augmented reality (AR) application was successfully developed, for the purpose of enhancing surgical instrument training, with most of the requirements identified from the initial user study being incorporated into the final prototype. The prototype application incorporates key elements which include grip zone highlighting, virtual 3D hand overlays, virtual surgeon's hand, orientation feedback and trajectory guidance. For this dissertation, the application was built for the Android platform and integrated Vuforia model-target object tracking alongside MediaPipe hand landmark detection. While technical limitations have reduced the accuracy of tracking surgical instruments in certain conditions and certain UI design elements could be further refined, the core functionality demonstrates the potential of the application to be used in a training environment.

During the beginning stages of application development, a different approach was taken for object tracking. This involved creating a custom dataset of physical surgical instruments for the purpose of fine-tuning a pre-trained real-time object detection model. However in hindsight, this approach would not have yielded adequate object-tracking performance as compared to training a Vuforia object detection model of a 3D instrument scan, due to challenges in recognising the instruments from different angles and position without a marker-based tracking approach. Had less time been spent pursuing this initial approach, more time could be allocated to fine-tune the functionality of the application. On the other hand, there were difficulties in using Vuforia model targets for object tracking due to the tracking being less reliable for reflective metal surfaces and so electrical tape was applied to the instruments in order to improve tracking. More time could also be allocated to exploring alternative tracking approaches, such as using stereo cameras for depth sensing. Additionally, the application could also benefit from integration of performance feedback metrics such as grip accuracy or the timing of instrument handovers. These features could add considerable value to the system and offer an opportunity for direct comparisons to traditional training methods, similar to suggestions made in the related literature for evaluating task performance of participants using AR or VR based tools [8, 38].

The application was intended for deployment on a dedicated AR headset, however time and availability constraints led to focusing on development for a smartphone-based platform. Nevertheless, the prototype demonstrated that mobile-based AR could provide an accessible, intuitive and portable solution for surgical instrument training. This is further enforced by feedback gathered through interviews and surveys, with medical professionals communicating strong enthusiasm and willingness to adopt AR tools in surgical education. The feedback also affirmed that traditional methods of training could be replaced with simulation-based training enhanced with interactive technologies. Furthermore, the user study highlighted the potential benefits that AR can provide in offering a repeatable, low-risk training environment that fosters confidence and helps novice medical professionals acquire skills that are transferable to the real-world surgical operating theatre.

The research undertaken as part of this dissertation, builds on the established findings that AR can improve spacial understanding and contribute to a refined user experience through real-time feedback and visual guidance [17, 33]. With regards to the methods reviewed for training and instrument handling procedures, these domains are consistently changing and can vary depending on location and dynamically changing safety rules. As an example different hospitals can have different variations on procedures for handling a specific instrument. This dissertation outlines only some of the procedures used for scrub nurse training and handling, but it does not seek to establish definitive rules for how surgical instrument training should be performed. Instead, this dissertation takes inspiration from recent forms of simulation training and established guidelines. It extends the body of reviewed literature, by focusing on the domain of hand-object coordination with surgical instruments, and designing a modular training experience that focuses on scrub nurse workflows. The prototype itself is a demonstration of the capabilities of AR in improving skill acquisition for surgical instrument training. This dissertation demonstrates the potential benefits of this prototype, justifying its use case in the surgical education domain whilst offering a foundation for future iterations to build upon this work.

5.1 Evaluation of Project Objectives

To assess the development outcomes, the objectives of the research were evaluated at the conclusion of this project. Table 1 illustrates the particular objectives set for the application and user study, as well as the reasoning behind the outcome of whether each objective was achieved or not.

On balance, the application prototype successfully achieved the majority of the functional and non functional objectives, which demonstrates the feasibility of AR for surgical instrument training. Despite some challenges faced with technical nuances and being able to achieve the original intended scope of all instruments, the resulting application provides the foundations for future development and expansion.

5.2 Future Work

Several areas for expansion and improvement are identified that can justify the use case of having an AR based surgical training tool.

- **Immediate Performance Feedback**
  Adding a score or performance metric at the end of each

Objective	Achieved?	Notes / Reason if Not Achieved
Develop an AR application to guide correct instrument grasping using visual overlays	Yes	Grip zones and virtual 3D hand models were implemented successfully.
Develop AR system to provide guidance during instrument handover	Yes	Orientation arrows and trajectory line were implemented with colour feedback.
Support training with five different surgical instruments	No	Only two instruments (scissors and scalpel) were fully implemented due to time constraints.
Deploy application on a hands-free AR headset (e.g., HoloLens)	No	Application was developed for Android smartphones due to hardware availability and time limitations.
Integrate real-time hand tracking to assess user grip	Yes	MediaPipe hand landmark tracking was successfully integrated to detect hand pose alignment.
Ensure robust object tracking on metallic instruments	Partially	Object tracking improved when applying electrical tape, but remained unreliable in certain lighting conditions.
Design an intuitive user interface for ease of learning	Yes	Designs were implemented based on positive feedback of initial mock-up designs presented to the users.
Conduct a user study to gather feedback on application usability and usefulness	Yes	Interviews and surveys were conducted with nine medical professionals.
Assess participant willingness to adopt AR for surgical training	Yes	Participants expressed strong willingness and interest in incorporating AR tools into training.
Evaluate participant design preferences for grasp and handover phases	Yes	Preferred visual aids were identified through survey results and incorporated into the prototype design.

Table 1: Evaluation of Prototype and User Study Objectives

tutorial could provide users with direct evaluations of their performance.

- **Improved Spatial Awareness Feedback** Adding visual markers or indicators for where objects in the AR space are placed, could provide better spacial understanding when using the application. This will enhance the safety aspect of the application by informing users where instruments are if the application was used in a clinical context.
- **Refinement of UI Design**
In its current iteration, the application prototype demonstrates the functional capabilities of supporting training, however the UI could be further optimised for smoother bug-free animations to further enhance the user experience.
- **Expansion to Other Instruments**
By extending the application to support a wider range of surgical instruments (e.g. forceps, clamps, needle holders), the system's training coverage would be widened to support additional skill acquisition.
- **Improved Object Tracking**
Additional research could be conducted into more robust object tracking solutions for reflective metallic instruments, that would enhance the reliability of the system in real-world conditions.
- **Deployment on AR Headsets**
The application could be adapted to target dedicated AR devices such as the Microsoft HoloLens 2 to create a more immersive training environment that is also hands-free.
- **Further User Studies**
Another user study could be conducted with a larger cohort of nurses, who could test the prototype application. This would provide deeper insights into the effectiveness and usability of the system, whilst offering opportunities for added features or refinement.

In conclusion, further research and development will be essential in order to expand upon the vision of using AR-enhanced training for clinical education. With the suggested areas of research and improvements, future iterations of the application can be more informative and more engaging for end users. These improvements can create a more tailored user experience as well as potentially inform other healthcare training domains to research, that could benefit from AR.

This project contains 9105 words from the introduction to the conclusion sections inclusively.

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