A comparison of surgical procedure cognitive skills acquisition between the traditional apprenticeship and a digital approach

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Research Article

Keywords: Cognitive skills, Surgical procedure cognitive skills, Surgical cognitive skills training, Surgical cognitive skills, Cognitive skills digital training

Posted Date: May 1st, 2023

DOI: https://doi.org/10.21203/rs.3.rs-2851859/v1

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Abstract

**Background:** The apprenticeship model of surgical training is the gold standard worldwide. However, increasing evidence shows that its traditional method of teaching surgical procedures covers cognitive skills inadequately. Therefore, the traditional teaching method for surgical procedures may be liable for producing surgeons who are not fully proficient in cognitive decision-making. This study designed a digital teaching method for surgical procedure cognitive skills and compared it to the traditional teaching method.

**Methods:** This was a quantitative experimental study conducted in two phases. Participants were novice medical officers and general surgery residents at the Universities of Botswana and Pretoria. Ethical approval was obtained. The digital teaching method was designed using the ADDIE model and compared to the traditional teaching method. ADDIE is an iterative instructional design model composed of five stages: Analysis, Design, Development, Implementation and Evaluation. A crossover-repeated-measures study design was used to determine the difference in knowledge gain and retention between the two teaching methods. A satisfaction level survey was also conducted.

**Results:** The digital teaching method for surgical procedure cognitive skills was designed and hosted on Moodle. Twenty-nine participants completed the study. The paired sample t-test showed that the mean differenced score for the digital teaching method (M = 3.59, SD = 1.48) was significantly greater than that of the traditional teaching method (M = 1.93, SD = 1.28), t (28) = -10.950, p < 0.001. Likewise, the mean differenced retention score for the digital teaching method (M = 2.96, SD = 1.480) was significantly higher than that of the traditional teaching method (M = 1.48, SD = 1.087). Seventy-two percent preferred the digital teaching method over the traditional one.

**Conclusion:** Students taught surgical procedure cognitive skills using the digital teaching method had better knowledge gain and retention than those taught using the traditional teaching method. Participants rated the digital teaching method highly compared to the traditional method. We recommend the adoption of the digital teaching method for teaching surgical procedure cognitive skills to produce surgeons competent in decision-making. The assumption is that this would lead to improved surgical outcomes.

1 Introduction

The apprenticeship model of surgical training is the gold standard worldwide. However, increasing evidence shows that its traditional method of teaching surgical procedures covers cognitive skills inadequately. Therefore, the traditional teaching method for surgical procedures may be liable for producing surgeons who are not fully proficient in cognitive decision-making. This study designed a digital teaching method for surgical procedure cognitive skills and compared it to the traditional teaching method.

**The inadequacy of traditional teaching method.**
The apprenticeship model of surgical training is practiced worldwide. It has its basis in a strong relationship between the trainer and trainee formed over many years of working together closely. In this training model, the method of teaching a surgical procedure entails a surgical trainee incrementally developing the skills required to perform an entire surgical procedure by repeatedly observing the trainer. The process is traditionally carried out in the operating room on live patients. A surgical procedure involves an incision with instruments to repair damage or arrest disease in a living body. This method of teaching a surgical procedure is summed up by the adage ‘see one, do one, teach one’. The trainee is expected to be capable of performing a particular surgical procedure after observing the trainer perform it, followed by being able to teach another trainee. This method of teaching a surgical procedure in the apprenticeship model is referred to as the traditional teaching method in this study. Unfortunately, studies have shown that 28–42% of trainees feel inadequately trained to perform surgical procedures safely after this teaching method. This is attributed to the emerging evidence showing that the traditional teaching method inadequately covers surgical procedure cognitive skills.

Surgical procedure training requires that one master the psychomotor and cognitive skills of a surgical procedure. The traditional teaching method emphasizes psychomotor more than cognitive skills. Psychomotor skills encompass motor activities and are primarily movement-oriented. Cognitive skills of a surgical procedure include higher-order thinking skills involving decision-making, error detection, and planning for a surgical procedure. Cognitive skills of a surgical procedure enable a surgical trainee to make safe critical decisions before, during, and after the procedure. Bloom's taxonomy provides educators with one of the first systematic classifications of cognitive learning processes. A brief review of the cognitive learning domain and cognitive skills is given to situate the research problem.

The cognitive learning domain is concerned with acquiring, retaining and using knowledge. It is commonly referred to as Bloom’s Taxonomy after Benjamin Bloom, who formulated the concept in 1956 with other researchers. It was later apportioned into six levels of increasing complexity. These six categories of cognitive skills range from lower-order cognitive skills requiring less cognitive processing to higher-order cognitive skills requiring deeper learning and greater cognitive processing. The six categories were knowledge, comprehension, application, analysis, synthesis, and evaluation. Bloom’s Taxonomy was subsequently revised and refined by Anderson and Krathwohl. Figure 1 provides a summary of the revised version of Bloom’s Taxonomy.

Bloom’s taxonomy is a cumulative hierarchical framework that requires the achievement of the prior skill before the next, more complex one. This should be born in mind by educators as they wish to develop learners’ cognitive skills to function at the higher levels described by Bloom’s Taxonomy. Complex tasks such as making a critical decision during a surgical procedure require one to have the ability to function at higher thinking levels incorporating various data points and, at times weighing and evaluating contradicting evidence. There are numerous learning taxonomies (such as Miller, SOLO, and Dreyfus). However, this study focuses on Bloom’s Taxonomy because it relies upon the
gradual increase in cognitive abilities and how they scaffold. These abilities should be sequentially developed.

Over the past three decades, the adequacy of the traditional teaching method in teaching surgical procedure cognitive skills has been increasingly questioned(12). Good judgement through critical thinking requires grounded cognitive skills.

Kohls-Gatzoulis asserts that Surgeons need to be trained to judge the correctness of their actions and that cognitive skills training enhances the ability to execute a surgical skill correctly(15). In his study, junior residents were randomized to two total knee arthroplasty (TKA) training course groups. One group was taught only technical skills and had more task repetitions (5 to 6), while the other focused on teaching cognitive skills and had fewer (3 to 4) task repetitions. An objective structured assessment of technical skills (OSATS) was done for both groups pre- and post-course. Both groups completed a pre- and post-course error-detection assessment to assess cognitive skills. The performance of both groups was equivalent for the OSATS technical skills assessment, but the cognitive group scored better in the error detection assessments: $t = 2.67, p = 0.02$. A take-home message from this study is that good technical skills due to operative caseload do not necessarily translate to good cognitive skills. Furthermore, cognitive skills training needs to be intentional and not assumed. Next, a review of the causes of the inadequacy of the traditional teaching method in teaching surgical procedure cognitive skills is provided.

One of the limiting factors in teaching surgical procedure cognitive skills in the traditional teaching method is how the training is conducted. Junior surgical trainees learn surgical procedures through observation in the operating room(13, 16, 17). An attempt to teach cognitive skills of a surgical procedure in the operating room prolongs the operation time and raises ethical and legal concerns regarding patient safety (30). Hence limiting the time available to teach cognitive skills during a surgical procedure. Even when educational opportunities present themselves in a clinical setting, they cannot be utilized because of the pressure for speed and maximum efficiency. This is compounded by overcrowded faculty and staff schedules(31).

Additionally, the traditional teaching method of surgical procedures in the apprenticeship model is unpredictable since it is based on available opportunities rather than structured pre-planned educational objectives(11, 12, 31). The knowledge acquisition for surgical trainees mainly depends on the available medical problems of the patients they care for(31). There are very few standardized and systematic instructional strategies to ensure that trainees are exposed to all surgical procedure cognitive skills during training(10, 12). Consequently, there is a lot of variation and omission of relevant information during the trainees’ instruction(31).

Research also indicates that expert surgeons typically omit up to seventy percent of the information about critical actions and decisions they make when training novices. As a result, they do not report how they solve problems or perform tasks during a surgical procedure(11, 12). The omission is attributed to this part of their knowledge being procedural (the how-to knowledge), which they have mastered and
comes automatically without a conscious effort. Most procedural knowledge is implicit and cannot consciously be recalled or explained. It becomes a stable component of a task over time and no longer requires conscious thought. Noel Burch called this type of procedural knowledge unconscious competence in his four stages of learning any new skill (32). Unfortunately, trainees must be taught this part of knowledge to understand why expert surgeons do things the way they do to build their own cognitive skills of the observed procedure.

Sullivan et al. elaborated on why the traditional teaching method in the apprenticeship model is inefficient in teaching surgical procedure cognitive skills (11). He demonstrated the unintentional omission of relevant procedural knowledge due to unconscious competence. He used cognitive task analysis (CTA) to capture steps and decision points that were not articulated during the traditional teaching of a colonoscopy. CTA gives access to the cognitive decisions that are made during procedural tasks and allows them to be broken down into discrete steps of a procedure that learners can understand. This is done through a series of structured interviews with a subject matter expert (SME). He video-recorded three expert colorectal surgeons during their traditional teaching of colonoscopy. The videotapes were later transcribed, and the experts participated in a CTA. A 26-step procedural checklist and a 16-step cognitive demands table were generated from information obtained in the CTA. The videotape transcriptions were transposed onto the procedural checklist and cognitive demands table to identify steps and decision points that were omitted during the traditional teaching. Surgeon A described 50% of “how-to” steps and 43% of decision points, Surgeon B described 30% of steps and 25% of decisions, and Surgeon C showed 26% of steps and 38% of cognitive decisions. This study demonstrates how significantly the unstructured and non-systematic nature of the traditional teaching method leads to the omission of relevant information.

Tirapelle et al. further elaborated on the omission of relevant information due to unconscious competence (12). He also used CTA to elicit knowledge from experts essential for comprehending a surgical procedure. The elicited knowledge was then used as instructional support for novice trainees. This elicited information would otherwise be omitted and not be transferred to the trainee during the traditional teaching method (12). The elicited information covered major steps, tasks and decisions employed to perform the surgical procedure effectively. He argues that this information enables novices to successfully process and organize a surgical procedure's actions and decision steps. Due to their extensive experience, expert surgeons perform tasks automatically without the need for conscious guidance or monitoring. Therefore there is no guarantee that a surgical trainer will teach a trainee all cognitive skills of a surgical procedure because of the automaticity inherent in unconscious competence (11, 12).

Arthur Whimbey concludes that many university students have weak thinking patterns because of a lack of systematic and sequential thought. Systematic and sequential thought, which is the ability to proceed through a sequence of analytical steps, is the foundation of all higher-order reasoning and comprehension (33). It is a cognitive skill (33). Systematically and sequentially training cognitive skills of a surgical procedure enables the trainee to climb the cognitive function ladder and perform at higher
levels (judgement and critical decision-making). Such an approach is lacking in the traditional method of teaching surgical procedures. A proficiency-based system should be used, where advancement is allowed once competence in subordinate skills has been achieved(34). For example, the trainees should demonstrate that they understand the steps of a surgical procedure outside the operating room before observing and performing it in the operating room. Novice trainees, in particular, experience challenges associated with the traditional teaching method. Such challenges include the inability to identify the most pertinent elements requiring greater attention. Secondly, they struggle to understand what happens during a surgical procedure in the operating room(35). Systematic and sequential training in surgical procedure cognitive skills is essential (11, 12, 31).

The literature on methods of teaching surgical procedure cognitive skills.

Grantcharov et al. recommended a sequential surgical procedure cognitive skills training that starts with acquiring knowledge specific to the procedure, including instrumentation, surgical anatomy, indications, complications, preoperative work-up, postoperative management, and successful completion of an assessment (29). This would then be followed by a video demonstration of the surgical procedure and an assessment of the understanding of the steps of the surgical procedure. He recommended that these steps precede an attempt to observe or perform a surgical procedure in the operating room.

The literature also suggests that educational videos effectively teach surgical procedure cognitive skills (36–39). Shariff et al. assessed the effectiveness of video as an educational tool for cognitive skills acquisition in open and laparoscopic colorectal surgery(40). Multiple operations were filmed, developed into procedural steps, and integrated into an interactive navigational platform using Adobe® Flash® Professional CS5 10.1. The teaching resource was availed online to general surgery trainees and compared with conventional teaching of cognitive skills. During an assessment survey, the video group improved their decision-making (67%) and factual and anatomical knowledge (88%), and 96% agreed that the video teaching tool was a useful cognitive skill teaching resource. The study concluded that video education was more effective for teaching cognitive skills in colorectal surgery.

In surgical training, the use of educational videos, such as recorded and 3D animation-generated videos, is not new. Video-based teaching methods are associated with significant knowledge retention, satisfaction levels, short training time and reduced learning duration (39, 41–43). These are welcome benefits to a surgical trainee who has to study while keeping up with a busy clinical schedule (38). In addition, 3D animation has been shown to facilitate the acquisition of cognitive (36–39) and technical skills (42). The illustrative power of 3D animation videos has particularly been demonstrated in the illustration of surgical anatomy(30, 44, 45). The dynamic topographic views of the surgical anatomy make the demonstration of the steps of a surgical technique realistic. Consequently, studies have suggested the use of 3D animation videos in teaching surgical procedures cognitive skills (14, 38, 46). The effectiveness of 3D animation video illustrations in surgical education is attributed to their visual realism (41, 47).
The past two decades have seen an evolution of 3D software enabling the creation of complex 3D models and animations (48). The animation of 3D models, when done well, conveys a large amount of information in a short space of time (48, 49). 3D animation is best for illustrations conveying an understanding of 3D spatial relationships (48). Such is true for surgical procedure training. Research has shown that the brain can absorb pictorial information better than text-based data (49). Students were also shown to learn more, remember content longer, and show more interest in learning when educational videos were used (50). Therefore the literature suggests that 3D animation has a vital role in surgical procedure training.

Additionally, assessments have been used in conjunction with teaching and learning activities (TLA) in cognitive skills training (12, 31, 33, 51). In most of these, they served the purpose of assessing the efficacy of a teaching intervention. However, there is another role for using TLA and assessments together. It is their joint contribution to achieving the intended learning outcomes, a concept described by Professor John Biggs in 1999 as constructive alignment (52). “Constructive” refers to the idea that students construct meaning from relevant TLAs, while “Alignment” refers to the situation whereby TLAs, and assessment tasks, are aligned to the intended learning outcomes (ILOs) (51). Intended learning outcomes must be set clearly at the beginning of learning, telling students what, how, and to what extent they have to learn. In constructive alignment, assessments facilitate learning instead of assessing learning. Assessments and instant feedback help cement learning, especially when spaced and spread throughout the TLAs.

In medicine, assessments were traditionally performed at the end of a module (modular tests). After completing all the modules, the marks are summed up or averaged; failure to achieve a set pass mark implies underperformance. This is called summative assessment. Summative assessment is an ‘assessment of learning as opposed to formative assessment, which is an ‘assessment for learning. The marks achieved by the learner after the summative assessment give limited information about the details of the strengths and weaknesses of the learner. Secondly, the limited feedback to the learner comes at the end of the module, denying them the opportunity to remedy their weaknesses (53, 54) and learn from their mistakes. Formative assessment involves continuous monitoring of a learner’s progress towards achieving specific outcomes through regular feedback and updates to the teacher and the learner. This directs teaching and learning continuously. Continuous assessment, as the name suggests, is more formative. It assesses learners over a period of time, and the learner’s abilities in specific areas are made cumulatively to facilitate further positive learning (55). Current learning theories emphasize continuous assessments and constructive, ongoing feedback to facilitate learning.

To conclude, the identified problem of the traditional method of teaching surgical procedures is: It inadequately teaches surgical procedure cognitive skills. The inadequacy stems from limitations resulting from the apprenticeship approach to teaching surgical procedure cognitive skills. These include limited time for teaching cognitive skills in the operating room, ethical concerns, dependency on available clinical opportunities that are not guaranteed, and unconscious competence that limits cognitive skills transfer from experts to novices. Therefore, there is a need for a reproducible, systematic, and sequential
approach to teaching surgical procedure cognitive skills to circumvent the mentioned limitations. Currently, there is very limited research that investigated reproducible, systematic, and sequential methods of teaching cognitive skills for surgical procedures. Therefore, there is a need to conduct research investigating such methods.

This study designed a digital method for teaching surgical procedure cognitive skills and compared it with the traditional teaching method. The digital method used 3D animation videos with embedded continuous assessments with instant feedback to teach surgical procedure cognitive skills.

The rationale.

The traditional teaching method may be liable for producing surgeons who are not fully proficient in cognitive decision-making as there is no reproducible, systematic, and sequential teaching of surgical procedure cognitive skills. If surgical trainees’ cognitive skills are well grounded, they can make critical decisions before, during and after the surgical procedures. The assumption is that not only will such trainees have lower surgical morbidity and mortality rates and consequently improved surgical outcomes, but they will also become better teachers.

I hypothesized that trainees who were taught surgical procedure cognitive skills using the digital teaching method would perform better than those taught using the traditional teaching method in terms of knowledge gain and self-reported satisfaction level. Furthermore, I hypothesized that the trainees would find the digital teaching method to be clearer. The complete training package was delivered to the trainees via a learning management system (LMS).

Aims and Objectives

This study sought to design a digital teaching method for surgical procedure cognitive skills using 3D animation videos and continuous assessment. It was implemented and evaluated by comparing it with the traditional teaching method. An outline of how the objectives of the aims were achieved is provided next:

1. To design the digital teaching method for surgical procedure cognitive skills.

The ADDIE model of instructional design was used to design the digital teaching method for surgical procedure cognitive skills. The first four stages of the ADDIE model were used to design the digital teaching method, and the last stage, the evaluation stage, to evaluate it by comparing it to the traditional teaching method.

2. To create teaching and learning content.

3D animation videos for surgical procedure cognitive skills were created using Autodesk® and Adobe® software packages. Assessments were created and embedded into the educational videos using the
Camtasia® software. Quizzes were also created using the Moodle quiz tool. The instant feedback logic was built into the education videos using Camtasia® software.

3. To implement and evaluate the effectiveness of the digital teaching method in teaching surgical procedure cognitive skills

The digital teaching method was piloted at the universities of Botswana and Pretoria and their affiliated hospitals. The digital teaching method for surgical procedure cognitive skills was evaluated by comparing it with the traditional teaching method regarding trainee knowledge gain, satisfaction level and surgical procedure clarity. Surgical procedure clarity referred to the participant’s perceived clarity of the teaching method in teaching surgical procedure cognitive skills. The knowledge gained was evaluated using pre-, post- and retention tests, while survey questionnaires were used to assess satisfaction level and surgical procedure clarity.

The next chapter details the methodology followed to achieve the outlined study objectives.

2 Material and methods

This study sought to design a digital teaching method for surgical procedure cognitive skills using 3D animation videos and video-embedded continuous assessments. The literature suggests that the traditional teaching method inadequately teaches surgical procedure cognitive skills. Surgical procedure cognitive skills are the ability of a surgeon to make critical decisions before, during and after a surgical procedure(19). Surgical procedure cognitive skills are a core competency essential for improving surgical morbidity and mortalities(56, 57).

This chapter presents the study’s methodology by detailing how it was designed and conducted to achieve its objectives. However, this is preceded by a presentation of how the researcher's philosophical beliefs and assumptions influenced the research methodology. The following research hypothesis was tested:

Novice surgical trainees who were taught surgical procedure cognitive skills using the digital teaching method would perform better than those taught using the traditional teaching method in terms of knowledge gain and self-reported satisfaction level. Furthermore, I hypothesized that the trainees would find the digital teaching method clearer.

The lens of positivism was used to frame the study. Positivism focuses on the objectivity of the research process(58) and mostly involves quantitative methodology(58, 59). Positivism aligns with the nature of the hypothesis. The researcher approached this study with a realist philosophical belief that truth can be discovered using objective measurements and can be generalized. This is in contrast to the relativist beliefs that there are multiple truths and that what is real depends on the meaning you attach to it and that truth is shaped by context and, therefore, cannot be generalized (60–62). Consequently, this study utilized a quantitative research methodology.
The definition of the terms, models and processes used in this study methodology is presented first. Then, the study design, choice and appropriateness of the statistics used and ethical considerations are covered. Finally, an in-depth study procedure detailing the steps taken during the study execution is outlined.

2.1 Definition of terms, models and processes.

The following terms, models and processes are defined, and their brief introduction is provided.

2.1.1 The ADDIE Model

The ADDIE model is a well-established instructional design model (63–65). It comprises five stages: Analysis, Design, Development, Implementation and Evaluation. An instructional design model aims to help educators optimally design and teach the appropriate material (66). The ADDIE model provides curriculum developers with a generic, systematic framework that is easy to use in various settings. It is a complete and iterative process with essential steps for developing an effective course or program (67). It has been found that using the ADDIE model leads to a content design that focuses on learning outcomes relevant to students and facilitates active learning (63–65). In addition, the ADDIE model informs high-quality instructional design. The analysis phase ascertains the need or gap for the course and determines what the course will be about. After stakeholder analysis, The educator identifies the training needs and core competencies that need to be developed. The educator compiles the Learning Outcomes that will inform the resources, facilitation and assessment. In the design phase, educators create a blueprint describing how to deliver the instruction to achieve the objectives identified in the analysis phase. During the development phase, the components of instruction are planned in detail towards the blueprint created during the design phase. During the implementation phase, educators deliver the instruction, with or without first implementing a pilot project. Finally, in the evaluation phase, educators obtain feedback about the program and make the appropriate adjustments to the program of instruction (66). While the phases are described in sequence, this is an iterative back-and-forth process between all phases during the instructional design. Figure 2 is a summarised, diagrammatic explanation of the ADDIE model.

2.1.2 Learning management system

A learning management system is a platform that automates training events' administration, participant analytics, and reporting and rapidly delivers learning content (68–70). It has the potential for individualized learning, to provide information at the point of need, facilitate self-directed learning and promote student-centred learning (68, 70). There are many commercial LMS options, including Moodle, Blackboard, and Brightspace, to mention a few.

2.1.3 The 3D Animation video production process.

The production of 3D Animation videos follows a standard production pipeline consisting of three main stages, namely pre-production, production and post-production (71). In addition, each stage consists of
sub-stages which may overlap. A brief account of the many stages of 3D animation video production follows. An explainer video is also available at https://youtu.be/0ZzaDxJk5oM

Pre-Production:

1. Ideate / The Idea. An individual starts with an idea or proposed solution to a problem. Good ideas may take years to develop.
2. Script. The idea is translated into a document format known as a script by a writer. The script details the narrative through the setting, character actions, dialogue, and camera framing, creating story information. The story information is broken down into scenes and shots. A scene is made up of several shots.
3. Storyboard. The script is converted into visual representations by storyboarding it. A storyboard is like a comic book in that several panels of sequential drawings maps the story. Here, scene blocking and camera moves are illustrated. Storyboarding may continue throughout the production as certain story elements may change.
4. Animatic. Storyboard panels are edited together, and narration and sound effects are added to see how it flows as a video. This is known as an animatic. It acts as a blueprint for the final edit and helps determine how much actual animation needs to be produced for each shot.
5. Previsualization. Instead of developing finished elements and footage at the start, digital stand-ins are used to help figure out camera positions, timing and movement in 3D space. Any obstacles that a shot may present can be worked out long before a lot of tedious effort has been put into the final product.
6. Design. The project signature style is developed. Guides are created to enable the digital sculpting of elements within the design parameters.
7. Modelling. 3D elements are modelled using a 3D software package (Autodesk Maya, Autodesk 3DS Max and Zbrush). There are several ways of modelling, including box modelling and sculpting from basic geometry such as spheres, cubes, cylinders and zspheres in Zbrush. The basic geometry is transformed into a new shape in 3D modelling.
8. Rigging. After completing the modelling of characters and scene objects, the models are rigged using bones and other rigging systems to allow their manipulation. It can be very tricky and laborious to ensure that the 3D mesh bends and folds in the desired fashion. Further rigging may be required for elements such as muscles, hair, clothes and even eyes.
9. Texturing. Digital models can be textured to almost any look, ranging from a solid colour to hand-painted or photographic imagery. This imagery is known as a map and can be projected onto a 3D model to simulate any imaginable surface. How light behaves across that surface (like reflection and transparency) is also controlled through texturing. The texture map can be extracted from the model and exported as a 2D texture map that can be modified and refined on a 2D graphic design software such as Adobe Photoshop. The refined texture map is then reimported and reapplied to the model. Complex texturing can take up to weeks.

Production:
1. Layout. Scene layouts are loosely based on their storyboard panels and closely based on their conceptual illustrations. Cameras and 3D models are set up in 3D space. Camera positions and motion are blocked out to establish strong composition for the animators.

2. Animation. The animator uses the rigged 3D character model to create motion by manipulating it and storing sequential poses of the model over time until a complete motion is achieved on a software timeline. The points on the timeline where the poses are stored are called keys. The software can then sequentially merge the individual poses stored as keys into a realistic animation. Almost all model attributes, such as colour, form, texture, light effects, position etc., can be animated. This gives 3D animation its dimensional look and realistic quality.

3. Lighting / Rendering. Physical lights are placed within the set and controlled for the desired final render. Rendering refers to the digital generation of the final appearance by a computer. This stage can be processor-intensive for the computer, depending on how many calculations the computer must do to produce the final 3-dimensional scene. Consequently, they are buildings filled with computers known as render farms for heavier processing. A single frame of high-definition 3D animation may take over a week to generate.

Post-Production:

Once the animation is rendered into a video, Final finishing touches are added to enhance the video. This can be anything from special effects to image enhancement to colour correction. In addition, music or voice overlay is done during this stage.

a. Effects. Effects such as smoke, a blade glow, explosion, dust, flame, etc., are added to make the animation more believable.

b. Compositing. The layering of several animation shots into a complete whole is called composition. It encompasses much more, including background removal and a new background addition.

c. Editing. Editing starts at the animatic stage to ensure the shots flow at an appealing pace. Then, as production advances, the editing process continues to refine the animation.

d. Audio. Sound and music may be added earlier in the production pipeline to set the mood. However, at the end of production, the original sound may be enhanced, edited or replaced to match the final animation. In addition, the audio overlay is usually added once the final pace of the animation is set for optimal synchronization.

It is worth noting that though the stages of video production are given in a sequence, many of them may overlap or occur simultaneously. Furthermore, some sub-stages may be omitted depending on the designer's style and the project size. In addition, the production team may have a modified production pipeline depending on their resources and experience.

The defined terms, models and processes will be referenced in the next section, which presents the study design followed in this study.
2.2 Study design

The study was conducted in two phases. Phase I of the study designed the digital teaching method for surgical procedure cognitive skills using 3D animation videos and continuous assessment. During phase II, the digital teaching method for surgical procedure cognitive skills was compared to the traditional teaching method. The compared variables were knowledge gain, satisfaction level and surgical procedure clarity. Phase I and II of the study are considered separately in the subsequent chapters and sections.

The first phase (Phase I) designed the digital teaching method using the first four stages of the ADDIE instructional design model defined in the preceding section. The ADDIE model is an established iterative process with essential steps for developing an effective course or program (63–65, 72, 73). The second phase (Phase II) occurred during the fifth stage of the ADDIE model, the evaluation stage. The latter stage compared the traditional teaching method (Intervention 1) to the digital teaching method (Intervention 2). Phase II, the evaluation stage, used a cross-over repeated measures study design to determine the difference in knowledge gained using pre-, post- and retention tests. In addition, the trainee satisfaction level and surgical procedure clarity were compared on a Likert scale using a survey questionnaire. Baseline information about the participants’ demographics and computer proficiency and needs assessment was also collected using survey questionnaires. Computer proficiency information was collected using an adapted and adopted computer proficiency questionnaire (CPQ-12), a validated and approved tool for training and research purposes used to assess computer proficiency(74).

The following sections cover phase I and II separately, starting with phase I, which deals with the designing of the digital teaching method of surgical procedure cognitive skills using 3D animation videos and continuous assessments.

2.2.1 Phase I: First four stages of the ADDIE model

Phase I of the study designed the digital teaching method of surgical procedure cognitive skills using the first four stages of the ADDIE instructional design model. The first four stages of the ADDIE model include the analysis, design, development and implementation stages. Phase I of the study addressed the first two objectives, which sought to design a digital teaching method for surgical procedure cognitive skills using 3D animation videos and embedded continuous assessments with instant feedback. 3D animation videos with embedded assessments will be created for four surgical procedures, namely: open appendicectomy (OA), mastectomy and axillary clearance (Mx & ANC), below-knee amputation (BKA) and inguinal hernia repair (IHR). The full process of the design of the digital teaching method of surgical procedure cognitive skills is documented and provided as annexure 1.

The last stage of the ADDIE model, the evaluation stage, will be covered next.

2.2.2 Phase II: The evaluation stage of the ADDIE model
The evaluation stage of the ADDIE models was conducted during phase II of the study. It involved the comparison of the digital and traditional teaching methods with regard to knowledge gain, satisfaction level, and procedure clarity. The comparison of knowledge gain used pre- and post-tests from which a differenced score was calculated as a measure of knowledge gained. Retention tests were also used to measure knowledge retention following each of the teaching methods. The comparison of knowledge gained after the two teaching methods was carried out by measuring the difference in knowledge gain between the two teaching methods using the repeated measures study design. A survey questionnaire was completed to assess satisfaction levels and procedure clarity. The satisfaction level and procedure clarity were compared on a Likert scale. Baseline information regarding the participants’ demographics and computer proficiency was also collected using survey questionnaires. Participants also completed another needs assessment form. The decision to have a repeat of the needs assessment was based on the fact that more health care centers were included and therefore more participants were expected to take part giving the results more statistical power.

Explanation of the crossover-repeated measures study design

Each participant made two random draws from a container with the names of four surgical procedures. The first draw corresponded to procedure ‘a’ and the second draw to procedure ‘b’. Participants were then randomly assigned to two groups (Groups A and B) according to their position in the enrolment order (1 - nth position). Group A consisted of odd-number positions (1, 3, 5, 7), and Group B had even-number positions (2, 4, 6, 8). Each participant in each group (A and B) was subjected to both the traditional and the digital methods of teaching the surgical procedures cognitive skills in a cross-over repeated measures design. When a participant was subjected to the repeated measures study design, if they were in group A, their first intervention (period 1) would be the traditional teaching method, and if in group B, it would be the digital teaching method. This design modification balanced out any advantage that may benefit a teaching method because it was the first intervention. This was achieved by having half of the participants start with one teaching intervention while the other half with the second intervention. For each participant, procedure ‘a’ cognitive skills were covered during the first teaching method (period 1) and procedure ‘b’ during the second teaching method (period 2). This ensured that different content was taught and assessed at period 1 and period 2 (procedures ‘a’ and ‘b’), minimizing the carry-over effect. The diagrammatic representation of the crossover repeated measures study design is shown in Fig. 3.

A pre-test was completed before the two teaching interventions (traditional and digital teaching methods), and a post-test was completed after each. The difference between the post-test and pre-test marks in periods 1 and 2 was called the differenced scores. The knowledge gained was measured using the differenced score. The differenced score was determined for both the traditional and digital teaching methods for everyone. This allowed the comparison of the differenced score for the two interventions for everyone. Two weeks after the post-test, the participants completed a retention test. After the participants were exposed to both teaching methods, they were required to complete a questionnaire on satisfaction level and procedure clarity using a Likert-type scale of 1–5.
The evaluation phase of the study was conducted on Moodle using a Moodle course layout that is tailor-designed to implement the study design. Because the study was solely administered online, the Moodle course layout needed to factor in the study design. Adaptive release and sequencing of teaching and assessment resources were important. These included educational videos with embedded assessments, tests for assessing knowledge gain (pre-tests, post-tests and retention tests), and survey questionnaires for assessing satisfaction and procedure clarity. The adaptive release was achieved by making course content on Moodle available to students only when they had fulfilled certain criteria. Moodle functionalities were used to sequence and selectively restrict access to learning resources. The Moodle course layout consisted of the following sections to enable the full online implementation of the study:

a. Access to the course was controlled through user login credentials. Each participant had login credentials which were given to them at enrolment.

b. Study Introductory information was available on the course for reference. At enrolment, the researcher also introduced the study to candidates.

c. The consent form was included for online signing.

d. Demographics, computer proficiency, and needs assessment questionnaires were completed online at registration.

e. Candidate assignment to study groups (A or B) and allocation of procedures a & b was conducted at enrolment and documented online.

f. Teaching and learning resources for the two teaching interventions and assessments (pre- and post-tests) were sequenced in the following order:

a. Pre-test

b. Intervention (digital teaching / traditional teaching method)

c. Post-test

d. Retention test

g. The satisfaction level and surgical procedure clarity questionnaire were completed online on Moodle.

Below is the layout of study content on the Moodle course layout for the online administration of the study.

- Executive summary

- The problem statement, hypothesis, aims and relevance.

- Participant’s information and informed consent
o Registration form (electronic form)

o Demographics questionnaire (survey)

o Computer proficiency questionnaire (survey)

o Needs assessment questionnaire (survey)

o Open appendicectomy
  
  - Pre-test (quiz)
  - Intervention 1 or 2 (digital teaching / traditional teaching method)
  - Post-test (quiz)
  - Retention test (after two weeks) (quiz)

o Mastectomy and axillary clearance
  
  - Pre-test (quiz)
  - Intervention 1 or 2 (digital teaching / traditional teaching method)
  - Post-test (quiz)
  - Retention test (after two weeks) (quiz)

o Inguinal hernia repair
  
  - Pre-test (quiz)
  - Intervention 1 or 2 (digital teaching / traditional teaching method)
  - Post-test (quiz)
  - Retention test (after two weeks) (quiz)

o Below knee amputation
  
  - Pre-test (quiz)
  - Intervention 1 or 2 (digital teaching / traditional teaching method)
  - Post-test (quiz)
  - Retention test (after two weeks) (quiz)

o Satisfaction & procedure clarity questionnaire

The following Moodle functionalities were used to build the adaptive release of the learning resources to conform with the study design.

a. Restrict access. This functionality is associated with each content/resource (quiz, questionnaire, videos, etc.). It allows the designer to create conditional statements for the adaptive release of TLAs.
b. Grouping. This functionality controls access to learning resources based on the group a participant was assigned to. Grouping according to procedure ‘a’ and ‘b’ drawn at enrolment is given in Table 1.

<table>
<thead>
<tr>
<th>Surgical procedure</th>
<th>Period 1 (a)</th>
<th>Period 2 (b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Open appendicectomy</td>
<td>a1</td>
<td>b1</td>
</tr>
<tr>
<td>2. Mastectomy and axillary clearance</td>
<td>a2</td>
<td>b2</td>
</tr>
<tr>
<td>3. Inguinal hernia repair</td>
<td>a3</td>
<td>b3</td>
</tr>
<tr>
<td>4. Below knee amputation</td>
<td>a4</td>
<td>b4</td>
</tr>
</tbody>
</table>

For instance, group a1b2 had open appendicectomy as the procedure taught during period 1 and mastectomy and axillary clearance taught during period 2 of the study design. Therefore, participants in this grouping only had access to open appendicectomy during period 1 and mastectomy only during period 2. This was achieved by building conditional statements for access TLAs of a surgical procedure. A participant in group a1b2 will be restricted from accessing inguinal hernia repair and below-knee amputation resources.

c. Attempts. This functionality was used to limit the number of attempts a participant had to attempt or view a resource.

The functionalities mentioned above were used to implement the cross-over repeated measures study design.

The Moodle course was created on the University of Botswana’s Moodle LMS. Placeholder content was used in place of the educational videos, tests and questionnaires during the researcher’s testing of the layout functionality. The course was reviewed with supervisors and tested. The snapshot of the course is shown in Fig. 4. The Moodle course layout functioned as intended.

Upon approval of the Moodle layout design, the digital teaching method (the educational video) was uploaded in their respective place in the Moodle course. The following evaluation assessments were developed and uploaded: questionnaires, pre-tests, post-tests and retention tests.

Developing questionnaires and tests.

The consent form and other questionnaire forms were developed using Moodle’s feedback resource. In addition, the computer proficiency assessment form was adapted and adopted from the computer proficiency questionnaire (CPQ-12), a validated and approved tool for training and research purposes used to assess computer proficiency(74).
A question bank with four categories of questions according to the four surgical procedures was created. Each category had questions assessing five of the six levels of Bloom’s taxonomy. The questions were reviewed and quality-checked by members of the Department of Surgery. The same process used during the design of questions for the embedded assessments was followed. The questions from the question bank were used to constitute the tests (pre-, post-, and retention tests) in the Moodle course layout. The link for the traditional teaching method in the Moodle course layout was populated with instructions for the participant to prepare for their allocated surgical procedure the same way they would when preparing to do or assist the surgical procedure in the operating theatre.

The researcher tested the Moodle course layout and setup for conformity with the crossover repeated measures study design. The final product was presented to the Supervisors for review and refinements made. Three such presentations were made, and the following refinements were suggested:

a. Collapsing the homepage to the level of Sections for it to look less busy.

b. To make it possible for the participants to indicate their confidence level for all the answers they give in all tests.

c. All tests to be restricted to a single attempt.

d. Not to give participants their score for their pre-test, post-test, and retention tests. This was to maintain the integrity of the subsequent tests since the questions came from the same question bank.

e. Allow the participants to view the digital teaching method videos up to 5 times before attempting the post-test.

The researcher amended the above using Moodle’s existing functionalities.

A final run was made using 2 senior residents and 2 members of the department of Surgery. No errors were found, and the project was approved for implementation.

The online project was removed from the test mode to the implementation mode. A video walkthrough of the online Moodle course layout and the sequencing of the teaching and learning resources is provided at https://youtu.be/9X_PvErhdNg

The enrolment of participants was started, and they were given user credentials to log into the University of Botswana Moodle LMS. The participants were introduced to the study and the Moodle interface at enrolment. The participants who consented to participate in the study completed the online consent form. However, if a candidate wanted to have access to the digital teaching method without participatin in the study, they were registered and given login credentials with a non-participant status. Access was only given to them after the completion of the study to avoid contamination of the study findings. The completion of the online consent form was followed by the assignment of surgical procedures (‘a’ and ‘b’) to participants and study groups A and B based on their enrolment position as described in the study
procedure. Participants then completed the demographics, computer proficiency, and needs assessment questionnaires. Each participant then scheduled their dates for study periods 1 and 2. The researcher implemented the Moodle course access control restrictions and assigned participants to groups, including their planned study activities. The researcher tracked participants' progress through Moodle's participant log history system.

2.3 The Study procedure

The digital teaching method for surgical procedure cognitive skills was designed using the first four stages of the ADDIE model of instructional design. After the design of the digital teaching method was completed, it was compared to the traditional teaching method during the evaluation stage of the ADDIE model (phase II of the study). During phase II of the study, the cross-over repeated measures study design was used to determine the difference in knowledge gained using pre-, post- and retention tests. In addition, the trainee satisfaction level and surgical procedure clarity were compared on a Likert scale. The satisfaction level and surgical procedure clarity were assessed using a questionnaire hosted on the LMS (Moodle). Participants’ baseline information regarding demographics, computer proficiency and need assessment was also collected using survey questionnaires. The entire study was conducted on the University of Botswana's Moodle LMS. The study procedure for phase II is elaborated next.

2.3.1 The procedure

The study was introduced to potential candidates, and a study information pamphlet was given to them to read and understand the study before deciding to participate in the study. The researcher’s telephone number and email address were included in the pamphlet for any further clarification that may be required. Upon freely expressing interest to participate in the study, by contacting the researcher, participants were enrolled. Participants were given login credentials to access and complete the online consent form. The autonomy of participants was respected, and where they were considered to have diminished autonomy, they were protected. There was no monetary reward, coercion, or undue pressure on the candidates. After enrolment, participants were anonymized in Moodle™. This was achieved through a setting on the Moodle Setup for making participants anonymous. It was made clear to the participants that should they wish to withdraw from the study for whatever reason, they were free to do so with no risk of being victimized.

Once the enrolment process was complete, the study design group assignments were carried out. Each participant made two random draws from a container with the names of four surgical procedures. The first draw corresponded to procedure ‘a’ and the second draw to procedure ‘b’. Participants were then randomly assigned to two groups (Groups A and B) according to their position in the enrolment order (1 - nth position). Group A consisted of odd-number positions (1, 3, 5, 7), and Group B had even-number positions (2, 4, 6, 8). The participants completed the demographics, computer proficiency and need assessment surveys at enrolment.
The commencement date for comparing the two teaching interventions was then scheduled. The grouping functionality on Moodle was used to allow each participant to have access to the two procedures (‘a’ and ‘b’) they randomly selected. The two procedures were also sequenced using Moodle’s access functionality by building conditional statements such that procedure ‘b’ only became accessible after completion of the retention test for procedure ‘a’. Participants were told to access instructions under the traditional teaching method link on Moodle for the traditional teaching method. The following sequencing was also explained to them:

Only the pretest of procedure ‘a’ was available at the beginning, after completing the pre-test, then the teaching intervention would be available. Upon completing the teaching intervention then, the post-test became available. Two weeks after completing the post-test, the retention test became accessible. The satisfaction level and procedure clarity surveys became accessible after the submission of the retention test. This was the online sequencing of the evaluation process.

The researcher kept in touch with participants and reminded them of their scheduled dates. If there were any need for postponement, the researcher would reschedule at the participant’s convenience.

Upon completion, the assessment section on Moodle became inaccessible, and a new section appeared where participants could view and use the digital teaching method for the four procedures.

The LMS grading system captured all the activities and results in its backend database.

2.4 Study site and sampling

The study sites were the universities of Botswana and Pretoria and their affiliated hospitals. Novice general surgery residents and medical officers who voluntarily participated in the study were included. A novice in this study refers to a newly qualified doctor entering a surgery department for the first time or surgical registrars in their first or second year of Registrarship.

Purposive sampling was used. The sample size was determined to be 24 (n = 24) for a 2x2 cross-over trial based on the treatment difference and the power of 80% at a 5% significance level.

2.5 Statistical analysis

Categorical data collected during the design phase was analyzed using frequency bar charts and frequency tables. The mean was used to describe the central tendency of the differenced scores. During phase II, the evaluation stage, the mean difference of the differenced scores for periods 1 and 2 was computed, and the significance of this difference was assessed using a dependent T-test, and the significance level was set at a p-value of 0.05. Frequency bar charts and frequency tables were used to describe the differences in satisfaction and clarity levels. The median and interquartile range were used to describe the central tendency of satisfaction and clarity level. IBM® SPSS® Statistics 25 software was used to do the statistical analysis, which was validated by a biostatistician.

3 Results
Phase I results are presented first and discussed before phase II results are presented and discussed.

### 3.1 Phase I: the instruction design using the ADDIE model.

The design of the digital teaching method for surgical procedure cognitive skills was completed using the ADDIE model of instructional design. It took six months to complete the design of the digital teaching method, an educational video with embedded assessment. Educational videos for four surgical procedures were produced. The educational video production was acThe four surgical procedures were: Open appendicectomy (OA), Mastectomy and axillary node clearance (Mx & ANC), Inguinal hernia repair (IHR) and Below knee amputation (BKA). Snapshots of the four completed educational videos with a series of thumbnails at the bottom are shown in Figs. 5–8.

#### 3.1.1 Embedded assessment for learning.

Each educational video had at least three embedded assessment events. The assessment events are shown in Fig. 9 along the timeline of the video as assessment events 1, 2, and 3. As the play head of the timeline reaches the assessment event, a pop-up message (1) would appear, allowing the participant to replay the last section of the video or take the embedded assessment. An example of an MCQ question is shown (2), and a wrong attempt with triggered instant feedback is also shown (3). After answering all the questions, a score summary is shown with the option to view all answers again or continue viewing the subsequent section of the video. If the participant had scored less than 50%, the ‘continue’ button would be ‘replay last section’, and the process would be started again.

Each educational video was reviewed by the Supervisors and members of the Department of Surgery four times before approval. The review meetings with the Supervisors were both physical and virtual. Review materials were submitted to Supervisors mostly via google drive. The following software were used during the production process: Autodesk Maya, Autodesk 3DS max, Zbrush, Adobe creative cloud software, especially Photoshop, Premier Pro, After Effects, Media Encoder, Audition and Captivate. Due to the complexity of the work, the researcher had to buy and learn new software, and these were, Handbrake and Camtasia®. Handbrake was easy to learn. However, learning to use Camtasia involved a steep learning curve.

The final educational videos were uploaded into the LMS during the evaluation stage (phase II).

#### 3.1.2 Discussion of Phase I results.

Phase I designed the digital teaching method for surgical procedure cognitive skills using 3D animation videos and embedded continuous assessments. There is ample evidence in the literature arguing that surgical procedure cognitive skills are not well covered in the traditional teaching model(11, 13, 14, 16, 17, 31). Yet, surgical procedure cognitive skills are essential for critical decision-making by a surgeon and are a core competency necessary for better outcomes in surgery(56, 57). In response, this study designed a digital teaching method for surgical procedure cognitive skills using the ADDIE model of instructional
design. The product of this design was an educational video with embedded assessments created using a 3D animation production pipeline.

A needs assessment yielded a unanimous agreement that there is a need for structured cognitive skills training before observing or performing a surgical procedure. This needs assessment survey was conducted during the analysis stage of the ADDIE model. Gallagher et al. recommended a similar method in which cognitive skills were trained before attempting technical skills in the operation room. A systematic approach suggested by the literature, which included introductory topics (surgical anatomy, indications, preoperative work-up etc.) and an illustration of the steps of the surgical procedure, was proposed. The trainees unanimously endorsed the proposal during the needs assessment survey. These results suggest that novice surgical trainees are aware of the deficiency in the traditional teaching method. Raîche et al. found that trainees raised a similar concern regarding their struggle to understand what happens during a surgical procedure in the operating room.

While some content development was relatively simple, some, especially 3D animation video production, required advanced technical skills and more resources. Eleven software were used during the complete 3D animation video production pipeline. Following an established production process was key, and being systematic during the production process was equally important. Best practices included setting up a good file and folder naming system and appropriately setting software units and working environments. Preventive measures such as turning on software autosave functionality and incrementally saving work avoided losing valuable work during a software crash. The 3D animation production pipeline is a time-consuming process but best practices and being systematic produced satisfying results. The researcher particularly found it important to set up the work environment appropriately before starting the 3D animation process. Finally, appropriately allocating hardware to tasks takes production to another level. The researcher had two high-performance computers allocated to the production pipeline. One for the pre-production and production processes and another for the postproduction process, which included rendering. Rendering is a highly computer-intensive job. A render may take 24 hours to complete.

The instructional design was completed but came with several challenges worth reflecting on. The difficulties encountered are outlined below, and how the researcher addressed them is also given.

i. The researcher required video editing software capable of incorporating quizzes within the educational videos and also generating instant feedback when the questions were attempted. The software needed to be able to restrict the participant from skipping answering assessment events embedded into the video. The participant needed to complete the embedded assessments and score above 50% for them to be able to proceed with watching the rest of the video. The researcher chose Camtasia software after doing some research and consulting. However, the researcher also had to learn how to use the software, so he did through tutorials on YouTube. It was a steep learning curve.

ii. The final video files tended to be larger in size, making uploading and sharing the video on LMS a challenge. After a quick online search, the researcher discovered a software called Handbrake, an open-
source video transcoder. It reduced the size of the video significantly with minimal loss of video quality.

iii. During the production process, especially the 3D animation video, the software occasionally crushed, and files would be lost or corrupted. This was especially the case during sculpting, 3D modelling, texturing and rendering. Incrementally and frequently saving work reduced the risk of losing all the researcher’s hard-earned work. The researcher also activated the software’s autosave functionality and increased the autosaving frequency. These two interventions ensured that there was always a recently saved file to start from without starting all over again.

The complete production of the four educational videos took four months. However, the researcher noted that subsequent work took a shorter period as more skills and experience were gained.

3.2 Phase II (Evaluation) Results

The evaluation stage compared the digital teaching method for surgical procedure cognitive skills to the traditional teaching method. The compared variables were knowledge gain, satisfaction level and procedure clarity. The knowledge gain was assessed using pre-, post-, and retention tests, while the satisfaction level and the procedure clarity were compared using survey questionnaires on a Likert scale. Participants’ baseline information regarding demographics, computer proficiency and needs assessment was collected using survey questionnaires. First is the presentation of the results of a LMS layout design designed to conform with the study design. The layout design was to allow complete online administration of the study.

3.2.1 The incorporation of the study design (cross-over repeated measures) into the LMS layout design

The evaluation of the two teaching methods was conducted on an LMS.

The LMS layout design on which the study was run factored in the study design (crossover-repeated measures) using the LMS functionalities. These LMS functionalities made it possible to sequence and control access to the study content in an adaptive release fashion, enabling it to be run entirely online. Figure 10 shows the completed online LMS course layout with uploaded content.

The designed digital teaching method was compared to the traditional teaching method during phase II (Evaluation) of the study, and the results are presented next.

3.2.2 Demographics

Thirty-five participants were recruited, 31 were enrolled, and 29 completed the study. Two of the thirty-one enrolled participants fell off the study and did not complete the study. The reason for their failure to complete the study was not known. The mean age of the participants was 31.5 years (SD = 3.74). Ten were general surgery residents, and 19 were medical officers in the departments of surgery. There were 10
females and 19 males. Participants' average time spent in the surgical departments was 1.9 years (SD = 1.36).

### 3.2.3 Computer proficiency

The findings of a computer proficiency questionnaire were as follows:

- All participants indicated that they used a computer every day.

- 27.6% (8/29) of participants indicated that they play computer games once a week, 18 once a month and three never.

- All participants had cell phones and laptops, 13.8% (4/29) additionally had desktops, and one had a gaming console.

Of the nine computer proficiency questionnaire items, all participants scored the highest on a Likert scale (1–5) for items 1,3,4,6,7 and 9 shown in Table 2. In general, the participants were computer literate, and all could easily watch movies and videos on a computer.

### Table 2

<table>
<thead>
<tr>
<th>Item</th>
<th>Computer proficiency questionnaire items</th>
<th>Likert Scale (1–5) Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>I can use a mouse</td>
<td>29</td>
</tr>
<tr>
<td>2</td>
<td>I can use a computer keyboard to type:</td>
<td>28</td>
</tr>
<tr>
<td>3</td>
<td>I can open e-mails</td>
<td>29</td>
</tr>
<tr>
<td>4</td>
<td>I can send e-mails</td>
<td>29</td>
</tr>
<tr>
<td>5</td>
<td>I can find information about local community resources on the Internet</td>
<td>26</td>
</tr>
<tr>
<td>6</td>
<td>I can find information about my hobbies and interests on the Internet</td>
<td>29</td>
</tr>
<tr>
<td>7</td>
<td>I can use a computer to watch movies and videos</td>
<td>29</td>
</tr>
<tr>
<td>8</td>
<td>I can use a computer to play games</td>
<td>14</td>
</tr>
<tr>
<td>9</td>
<td>I can use a computer to listen to music</td>
<td>29</td>
</tr>
</tbody>
</table>

### 3.2.4 The learner needs assessment survey

The learner needs assessment survey was completed again during phase II of the study. During Phase II, there were 29 participants compared to 23 during Phase I. This was because during phase I, not all University affiliated hospitals were recruited due to distance and COVID-19 constraints.
The needs assessment revealed that all participants thought all the listed topics should be covered before a trainee assists/perform a surgical procedure. All participants indicated that the demonstration of surgical procedure steps should be covered in detail before assisting or performing it. Additionally, 93.1% (27/29) indicated that pre-operative preparation and post-operative management should be covered in detail. Ninety-seven percent (28/29) felt the same about postoperative complications and their management. Table 3 shows the results of the needs assessment survey.

### Table 3
Needs assessment survey results.

<table>
<thead>
<tr>
<th>Topics</th>
<th>Is it relevant to cover the topic before doing/assisting the surgical procedure in the operating room?</th>
<th>To what extent should the topic be covered?</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>1. Introduction to the surgical procedure</td>
<td>29</td>
<td>0</td>
</tr>
<tr>
<td>2. Indications for a surgical procedure</td>
<td>29</td>
<td>0</td>
</tr>
<tr>
<td>3. Contra-indications for a surgical procedure</td>
<td>29</td>
<td>0</td>
</tr>
<tr>
<td>4. Preoperative preparation</td>
<td>29</td>
<td>0</td>
</tr>
<tr>
<td>5. Demonstration of positioning</td>
<td>29</td>
<td>0</td>
</tr>
<tr>
<td>6. Demonstration of exposure and access</td>
<td>29</td>
<td>0</td>
</tr>
<tr>
<td>7. Demonstration of operative steps</td>
<td>29</td>
<td>0</td>
</tr>
<tr>
<td>8. Demonstration of closure</td>
<td>29</td>
<td>0</td>
</tr>
<tr>
<td>9. Postoperative management</td>
<td>29</td>
<td>0</td>
</tr>
<tr>
<td>10. Complications and their management</td>
<td>29</td>
<td>0</td>
</tr>
</tbody>
</table>

### 3.2.5 The difference in knowledge gain

The differenced score was calculated as the difference between the post-test and the pre-test scores. A second score, the ‘differenced retention score’, was calculated as the difference between the retention test and the pre-test scores. The pair of the differenced scores (pair one) and the differenced retention scores (pair two) for the digital and the traditional teaching methods are shown in Figs. 11 and 12, respectively.
The differenced scores (pair one) were a measure of the improvement score as a result of each intervention (teaching methods). The differenced retention score was a measure of the improvement score as a result of retained knowledge after two weeks following an intervention. It is used as a surrogate measure of how well the participants retained knowledge for two weeks due to an intervention. It gives an estimate of each teaching method's role in the subjects' retention capacity.

A paired sample T-test analysis was used to assess the significance of the difference between the mean differenced scores of the digital and the traditional teaching methods in pair one. Additionally, the significance of the difference between the mean differenced retention scores of the digital and the traditional teaching methods in pair two was also determined using the paired sample T-test.

The following assumptions were made for the paired sample T-test analysis to be valid:

1. The dependent variables must be continuous and measured at interval or ratio levels. The condition was met as shown in the table.

2. The observations should be independent of one another. The condition was met because two different procedures were used during periods 1 and 2 to avoid a knowledge carryover effect.

3. The dependent variable should be approximately normally distributed, and

4. The dependent variable should not contain any outliers. Figures 13 and 14 show that the differenced scores and the differenced retention score for the digital and traditional teaching methods are normally distributed with no outliers.

The paired sample t-test showed that the mean differenced score for the digital teaching method (M = 3.59, SD = 1.48) was significantly greater than that of the traditional teaching method (M = 1.93, SD = 1.28), t(28) = -10.950, p < 0.001 (two-tailed). Likewise, the mean differenced retention score for the digital teaching method (M = 2.96, SD = 1.480) was significantly higher than that of the traditional teaching method (M = 1.48, SD = 1.087). 72% (18/25) preferred the digital teaching method over the traditional one.

Table 4 shows the paired samples T-test results for pairs 1 and 2.
3.2.6 Satisfaction level and procedure clarity assessment

A 12-item satisfaction level and surgical procedure clarity assessment using a Likert scale rating of 1–5 was used. Table 5 shows each rating frequency by 25 participants for each of the 12 items of the questionnaire. All participants strongly agreed that they were satisfied with the digital teaching method, while 24 out of 25 strongly agreed that they would recommend it to a colleague and its adoption. In all the 12 questionnaire items, there was a favourable rating of the digital teaching method over the traditional one in teaching surgical procedure cognitive skills. This assessment was on level 1 of the Kirkpatrick Model. It was learner-focused and evaluated the learner's satisfaction with the efficacy of training(80).
Table 5
Rating frequencies for each item of the satisfaction level and procedure clarity

<table>
<thead>
<tr>
<th>Item No.</th>
<th>Satisfaction level and procedure clarity questionnaire items</th>
<th>Likert scale</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>1</td>
<td>There was no confusing information in the traditional teaching method</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>There was no confusing information in the digital teaching method (Video illustration)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>Information was presented logically in the traditional teaching method</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>Information was presented logically in the digital teaching method (Video illustration)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>The traditional teaching method helped me to better understand the topic</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>The digital teaching method (Video illustration) helped me to better understand the topic</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>I feel like the traditional teaching method helped me achieve the learning outcomes.</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>I feel like the digital teaching method (Video illustration) helped me achieve the learning outcomes.</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>Overall, I am satisfied with the traditional teaching method.</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>9</td>
<td>Overall, I am satisfied with the digital teaching method (Video illustration).</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>I would recommend the digital teaching method (video illustration) to a colleague</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>11</td>
<td>I recommend the adoption of the digital teaching method (video illustration)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>12</td>
<td>Assessments in the digital teaching method (Video illustration) facilitated learning.</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

3.2.7 Discussion of Phase II results

This study sought to design an alternative digital teaching method for surgical procedure cognitive skills using 3D animation videos and continuous assessment. This was in response to the suggestion by the literature that surgical procedure cognitive skills are inadequately covered by the traditional teaching method despite their significance in improving surgical outcomes(11, 13, 14, 16, 17, 31, 56, 57).

The digital teaching method was designed and evaluated by comparing it with the traditional teaching method. The complete training package was delivered to the trainees via a LMS. This study focused on the training of surgical procedure cognitive skills.
Evaluation of the teaching methods (Phase II)

The choice of Moodle as a LMS in this study was based on the researcher’s experience with using the LMS, from a previous study (81). Additionally, the LMS is used by the University of Botswana. Therefore, there is available support from the University’s IT department. The support rendered by the institutional Information and Technology (IT) department was particularly important in this study. The IT department manually created a new standalone course to allow the researcher to enrol non-UB participants into the course on the University’s LMS without interfering with the mainstream courses.

All participants had their computer proficiency assessed, and they had the basic computer skills required to participate without being disadvantaged. These included their ability to use a mouse and keyboard, listen to music on a computer and search/navigate the internet (74). These computer skills allowed the participants to interact with the LMS course without limitations.

Ninety-seven (97)% of participants were found to have more knowledge gained in surgical procedure cognitive skills after being taught using the digital teaching method than the traditional one. Likewise, participants were found to have greater knowledge retention after the digital teaching method compared to the traditional one. These findings suggest a better understanding and knowledge retention with the digital teaching method. These findings were more attributable to the interventions because of several factors related to the study design (82). First, the study was well-powered, with a larger sample size than the calculated minimum sample size. By its nature, the repeated measures study design requires a relatively smaller sample size. Furthermore, the group served as its own control, minimizing the variability of the results and favouring their validity. Third, the carryover effect, a weakness of this study design, was minimized by assessing the knowledge gain for two different surgical procedures in periods 1 and 2. Another weakness of the study design that was minimized was the bias due to the treatment order. This occurs due to fatigue and the carryover effect mentioned above. To minimize the bias, half the participants started with Intervention 1, while the other half started with Intervention 2 to cross out the impact by equally distributing it between interventions. The reduction of these confounders made the findings in this study more attributable to the compared interventions. Finally, serious attrition of participants over multiple interventions can occur (82). However, this was not the case in this study, as we started with 31 participants, and only two stopped participating. Our sample size was still more than the calculated minimum sample size. The researcher also settled for a two weeks’ time lapse before the retention test was conducted to reduce the risk of a high attrition rate.

The paired T-test evaluation results’ validity required that the differenced scores be normally distributed without outliers (79). Using the graph assessment, the variables were normally distributed. However, the Kolmogorov-Smirnov and the Shapiro-Wilk showed that all were indeed normally distributed. There were no outliers. Our study findings were similar to other studies regarding better knowledge gain with digital than traditional teaching methods (36–39). Therefore, the new teaching method is a viable alternative to teaching cognitive surgical procedure skills.
Out of the 29 participants, only 25 completed the satisfaction level and procedure clarity assessment survey. The reduced number of participants who completed the survey may be a sign of study fatigue. Generally, the participants were more satisfied with the digital teaching method relative to the traditional teaching method regarding the teaching of surgical procedure cognitive skills. They also considered the digital teaching method clearer than the traditional one. Previous studies have produced similar findings (39, 41–43). However, this study did not seek to discover why participants had such high satisfaction levels and ratings for the clarity of the teaching method. A shorter learning duration has been shown to be one of the desirable factors of digital teaching methods (39, 41–43). Further studies are needed to define factors that make digital education more likeable.

The Study limitations

The researcher acknowledges the following limitations of the study:

• The participants were alone when attempting the tests online and could easily have been cheating. There is no reason, however, to believe that they would particularly do so in favour of one teaching method.

• There were more medical officers than surgical registrars. However, the measured determinant of knowledge gain is not reflective of previous knowledge but the difference between initial knowledge and knowledge gain attributable to the intervention. Therefore, the difference between the pre-test and post-test scores, the differenced score in this study, was used to measure knowledge gain. The assumption is that the effect of a participant’s position and pre-existing knowledge is minimal.

• There is a potential that candidates did read before attempting the retention test, therefore, scoring higher on the retention test. However, this possibility was true for both interventions; thus, the effect would have crossed out.

All things considered, the findings are suggestive that the digital teaching method is more effective than the traditional teaching method in teaching surgical procedure cognitive skills. It is consistent in quality, the message delivered and content. Therefore, it remains a viable alternative for teaching surgical procedure cognitive skills.

4 Conclusion

This study was conducted in response to the emerging evidence highlighting the inadequacy of the traditional teaching method of the apprenticeship model in teaching surgical procedure cognitive skills. It set out to design a digital teaching method for surgical procedure cognitive skills using 3D animation videos and continuous assessment. The efficacy of the digital teaching method was assessed by comparing it to the traditional teaching method. Students taught surgical procedure cognitive skills using the digital teaching method had better knowledge gain and retention when compared to those taught using the traditional teaching method. In addition, participants were more satisfied with the digital teaching method than the traditional one in teaching surgical procedure cognitive skills. Additionally, they
considered the digital teaching method clearer than the traditional one. Ninety-two(92)% highly rated the logical presentation of content in the digital teaching method compared to 16% for the traditional method. Furthermore, 96% gave the digital teaching method the highest rating for helping them better understand the subject being taught compared to 4% for the traditional teaching method. The researcher recommends adopting the digital teaching method for teaching surgical procedure cognitive skills to produce surgeons competent in decision-making. The assumption is that this would lead to improved surgical outcomes.

Declarations

Ethics approval and consent to participate

All the experiments in this study were conducted in accordance to the Declaration of Helsinki. Ethical approval was obtained from the Research Ethics Committees, Faculty of Health Sciences and the University of Pretoria, University of Botswana and Ministry of Health Botswana. The study was introduced to potential candidates, and a study information pamphlet was given to them to read and understand the study before deciding to participate in the study. The researcher's telephone number and email address were included in the pamphlet for any further clarification that may be required. Informed consent was obtained from all subjects participating in the study. Additionally, information was availed online regarding the research proposal to enable candidates to make informed decisions. Upon the expression of intent to participate, participants were given login credentials to access and complete the online consent form. The autonomy of candidates was respected, and where they were considered to have diminished autonomy, they were protected. There was no monetary reward, coercion, or undue pressure on the candidates. After enrolment, participants were anonymized in Moodle™. This was achieved through a setting on the LMS Setup for making participants anonymous. It was made clear to the participants that should they wish to withdraw from the study for whatever reason, they were free to do so with no risk of being victimized.

After the study, access to the digital teaching method was granted to all candidates for a year. Candidates were free to request for access, while not participating in the study, and they would be assigned a non-participant LMS account to avoid contamination of the study results.

Consent for publication

Not applicable

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests
The authors have no conflict of interest

**Funding**

None

**Authors' contributions**

M.M. conceived the work, collected data, analyzed, interpreted, drafted, and was involved in revising it critically for important intellectual content. Took part in the final approval of the version to be published and agreed to be accountable for all aspects of the work, ensuring that questions related to the accuracy or integrity of any part of the work were appropriately investigated and resolved. MB and IL were involved in drafting the work, analyzing and interpreting it, critically revising it for important intellectual content and approving the final work to be published. LM was involved in drafting the work, statistical analysis and interpretation of the data, critically reviewed the statistical soundness of the analysis and was involved in the approval of the version to be published.

**Acknowledgement**

This project could not have materialised without the support and motivation of my wife, Dr Marang Motsumi, who encouraged me to develop my passion into a PhD project. My sincere gratitude goes to Professor Daniel Montwedi, who identified and directed me to the capable hands of Professor Martin Brand as the right person to be my supervisor. The choice was right, and the seed landed on fertile ground. Professor Martin Brand understood my dream and vision. He constituted a team of unformidable supervisors with immense knowledge in the subject of my study by pulling in Dr Irene Lubbe. Her expertise in medical education took the project to another level. The supervision I received was focused, thorough and consistent. A big thank you to my supervisors. I also want to thank Dr Lucky Mokgatle, a seasoned statistician who selflessly provided statistical support and guidance. I am truly indebted to my Supervisors.

I thank my friends and family, especially my three beautiful daughters. You were and are my pillar of strength during trying times. Thank you.

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Figures

![Figure 1](image-url)

**Figure 2**

A diagrammatic representation of the ADDIE model of instructional design [created by Florida State University].

**Figure 3**
A complete representation of phase II study design.

Figure 4

The online Moodle course.
Figure 5
Legend not included with this version

Figure 6
Legend not included with this version

Figure 7
Legend not included with this version

Figure 8
Legend not included with this version
Figure 9

Interactive options of the video-embedded assessment.
Figure 10

Snapshot of the complete Moodle course.
Figure 11

The differenced scores for the two teaching interventions
Figure 12

The differenced retention scores for the two teaching interventions

Figure 13

Normally distributed differenced scores for the teaching methods.

Figure 14

Differenced retention scores for the teaching methods.

Supplementary Files
This is a list of supplementary files associated with this preprint. Click to download.

- Annexure1.PhaseITheADDIEModel.docx