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# Redefining Surgical Skill Acquisition

*Vaikunthan Rajaratnam, Norana Abdul Rahman,  
Chaoyan Dong and Hannah Jia Hui Ng*

## Abstract

There have been reduced opportunities for surgical skill acquisition due to the COVID-19 pandemic and the regulated training hours. Despite these challenges, self-regulated learning allows trainees to learn continuously, and motor skills development can be augmented through mental practice and motor imagery. The aim of this chapter is to introduce the theoretical concepts in skill acquisition and the role of mental and deliberate practice as an alternative for skill training. A case study is presented using a design and development framework for producing an online basic micro suturing training resource based on self-regulated learning. This case study demonstrates the use of the ADDIE instructional design model and Mayer's multimedia theory guidelines, for creating online instructional resources. The methodological approach of a design and developmental framework to create an educationally sound online training module for micro suturing which has significant utility in hand surgery is discussed in this chapter. The tools described in this chapter are translatable to any psychomotor skills development in medical education.

**Keywords:** micro suturing, mental script, mental practice, motor imagery, deliberate practice

## 1. Introduction

The transformative changes occurring in the technology, political and economic landscape has not spared medical education (ME), which is further compounded by the ever-increasing knowledge and skills in medicine. The last few decades have seen an increasing expectation in the efficient utilisation of resources in ME. Despite all these changes and investments, doctors who are fit to practice competently in the community remain a challenge – lacking in the soft skills of medical practice and the hard skills of knowledge and procedural skills. It has been documented that ME has failed to meet the community's needs altogether [1]. There is a call by all transdisciplinary stakeholders for value for money, universal access, and increased quality of care, and this has impacted the medical education field, including suggestions to adopt a transdisciplinary and transnational approach to designing and delivering competency-based medical education. This requires an alignment and integration of medical education to quality of care to patients and populations with a sense of accountability founded on social justice [2].

Surgery as a specialty is dependent on psychomotor skills and has traditionally followed a mentor-apprenticeship model where experienced surgeons train

the learners in the work environment [3] to produce surgeons who are competent in specific motor skills within a stipulated time. Learners need to aspire to excellence in the interest of their patients [4]. The traditional surgical training models, including mentoring, role-modelling, and one-to-one supervision, produce skilled and competent surgeons. However, this mode of teaching is vanishing due to time constraints and the heavy burden of service commitment to meet the needs of the community [5, 6]. The emphasis on service efficiency has curtailed on-the-job teaching and exposure to live patients in the current hospital environments. Innovative strategies have been adopted to make the programmes more flexible and efficient, more trainee-oriented, incorporating innovations like simulation technology, competency-based assessments, online learning, and resources, emphasizing teamwork, professionalism, communications, and quality patient care [7]. The aim of a surgical training is to produce competent surgeons skilled and safe, who fulfill the community’s needs [8–11].

2. Theoretical models for surgical motor skill acquisition

Advancement in surgical education research sheds light on the understanding of competency and assessment, in the sense that competency cannot be assumed when trainees can perform parts of a task or individual surgical skills, as many complex tasks require the integration of many skills. Literature showed that surgical trainees at both undergraduate [12] and postgraduate levels [13] do not feel competent or ready to operate independently at the end of their training. Competence is not equal to excellence. Due to the lack of time and opportunities to practice, the learning process focuses on competence rather than excellence [14]. For surgical motor skill acquisition, the following four theoretical models are commonly used (**Table 1**) - Fitts and Posner’s 3-Stage Model of Motor Skills Acquisition, Bandura’s Theory of Social Learning, Ericsson’s Deliberate Practice Model, and Motor Simulation Theory of Jeannerod.

Mental practice (MP) is “the cognitive rehearsal of a task in the absence of overt physical movement” [19]. It has successfully improved psychomotor performance to enhance skill and performance in sports and music [20, 21]. Mental imagery (MI) has been shown to activate similar neural processes to those used in the actual performance of a given skill [22, 23]. MP has been used lately as an alternative strategy in surgical training. The current literature shows the successful use of MP in surgical training or enhancing surgical performance, but lacks methodological details for the development of educational resources incorporating MP.

Theory	Summary
Fitts and Posner’s 3-Stage Theory of Motor Skill Acquisition [15]	Motor skill acquisition goes through 3 stages, i.e., cognitive or learning stage, associative or motor behaviour stage, and autonomous or expert stage.
Bandura’s Theory of Social Learning [16]	Based on observational learning and modelling: attention, internalisation or retention, reproduction, and motivation
Ericsson’s Deliberate Practice Model [17]	Deliberate practice in motivated individuals with regular reinforcement and feedback to support learning
Motor Simulation Theory of Jeannerod [18]	Cognitive rehearsal of a task in the absence of overt physical movement using script-based mental rehearsal

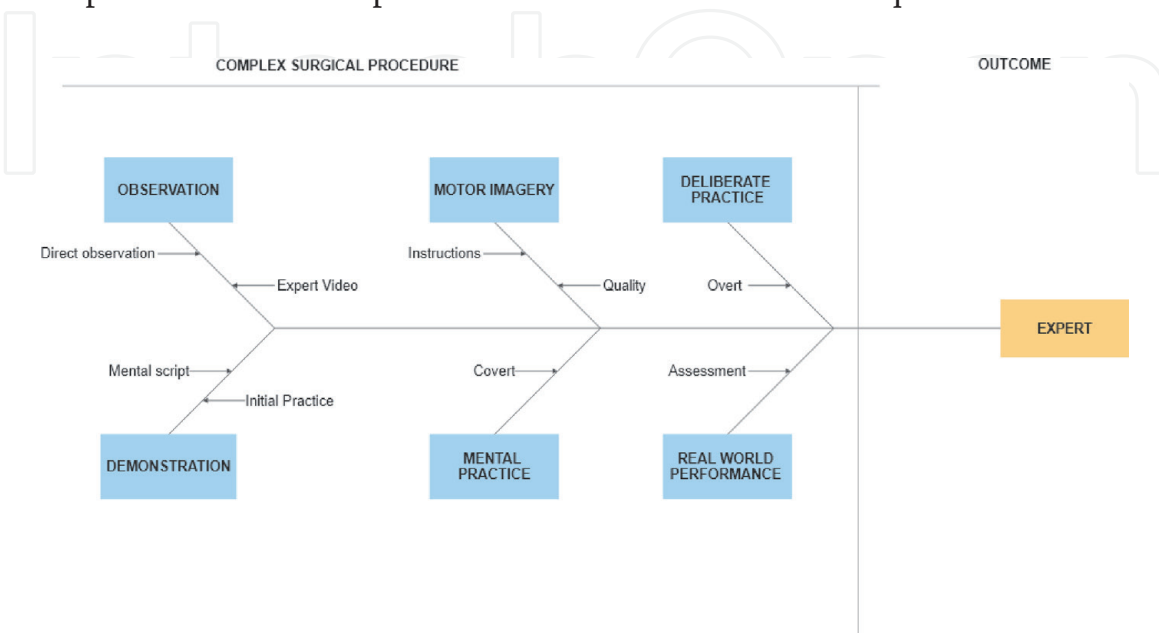
**Table 1.**  
*Summary of surgical training theories.*

In summary, the current body of knowledge on psychomotor skill acquisition to an expert level [24, 25] requires:

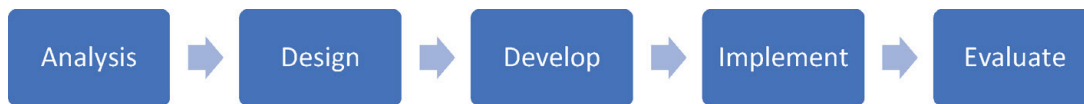
- observation of the skill demonstrated by an expert
- internalisation with motor imagery
- mental practice and repetition
- physical deliberate practice

The current model of surgical training programmes for motor skill acquisition focuses on the direct supervision of the expert in the operating room, providing direct observation, guidance, and feedback, ensuring compliance to the pre-operative plan. Graduated responsibility and progression in surgical performance are allowed based on the level of surgical performance and adherence to patient safety [26]. The emphasis has been the development of competencies which is a minimum level of skill to be demonstrated, rather than mastery associated with a higher level of proficiency. Competency requires much less training than mastery and is facilitated by the very structured and focused training. Hence, to overcome the reduced opportunity to learn and practice in the operating room, low fidelity bench models, basic surgical skills, surgical laboratory practice, and higher fidelity human cadaver models to live animal model practice have been utilised [27]. From simulation to gaming and robotics, technology has also become the enabler in surgical training [28, 29]. These strategies have implications in cost-effectiveness and universal accessibility, as they require resources - both physical and trainee/trainer time, as they are synchronous platforms for learning [30]. However, the current model is singularly deficient in that there is no universally accessible opportunity to practice the surgical procedure outside of the operating theatre and without access to physical simulators.

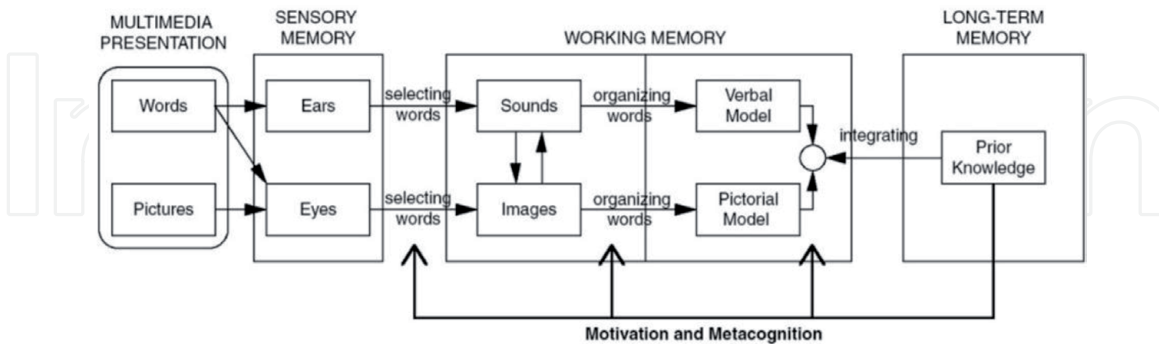
Based on the review of these theoretical frameworks, we propose a model for the expert acquisition of motor skills in **Figure 1**. This model incorporates the theoretical framework of Fitts and Posner, Bandura, Ericsson, and Jeannerod, and operationalises the steps described in the theories of skill acquisition and



**Figure 1.**  
*An integrated model for surgical skill acquisition.*



**Figure 2.**  
*ADDIE instructional design model.*



**Figure 3.**  
*Mayer's cognitive theory of multimedia learning.*

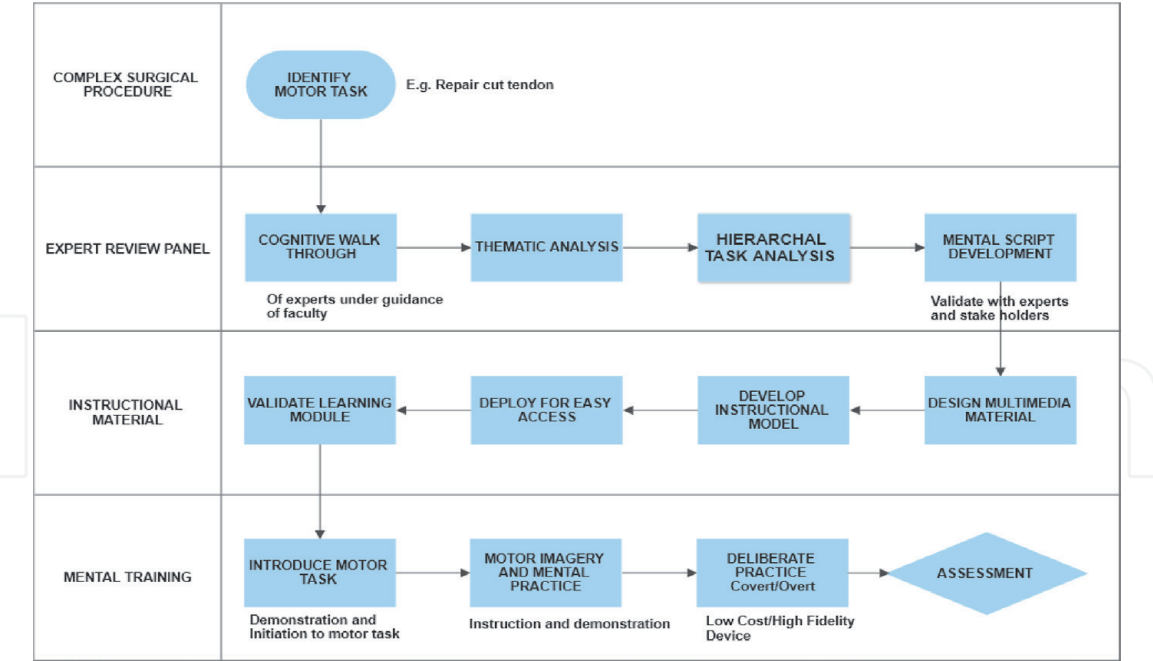
mastery [15–18]. The observation of expert performance, with an introduction and performance of the task by the trainee, followed by mental practice with motor imagery augmented with deliberate practice, will need further authentication and validation.

More importantly, this model highlights the importance of applying instructional design models to create instructional materials and programmes for surgical skill acquisition. Instructional design (ID), the science of instruction, provides a systematic and evidence-based methodology for creating instructional materials for effective teaching. The various models and techniques have been used in surgical training [31–33].

A commonly used ID model for designing learning programmes is the Analysis, Design, Development, Implementation, and Evaluation (ADDIE) model in **Figure 2** [34] coupled with Mayer's cognitive theory of multimedia learning [35] in **Figure 3**. They can provide the framework for designing training programmes and materials for skill acquisition, which promotes mental simulation with deliberate practice in surgery training. Mayer's multimedia learning theory defines principles using texts, images, and audio to improve knowledge and skills acquisition. The theory explains how people learn through multiple sensory stimuli rather than a single channel such as texts, and empirical evidence showed that adding images and videos to words improves learning outcomes [36]. In addition, multimedia learning theories indicate best practices in designing multimedia teaching materials [37].

### 3. Our proposed model

The execution of the model – our proposed tool shown in **Figure 4** describes the use of a design and development research framework to produce instructional materials incorporating mental and deliberate practice. It describes the use of the expert review panel and in-depth interviews to identify the key tasks of complex surgical procedures from the expert's perspective. Incorporating a think-aloud/verbal walkthrough of the index motor skill by experts, followed by content and task analysis [38], allows for creating a detailed mental script to be incorporated into the instructional materials.



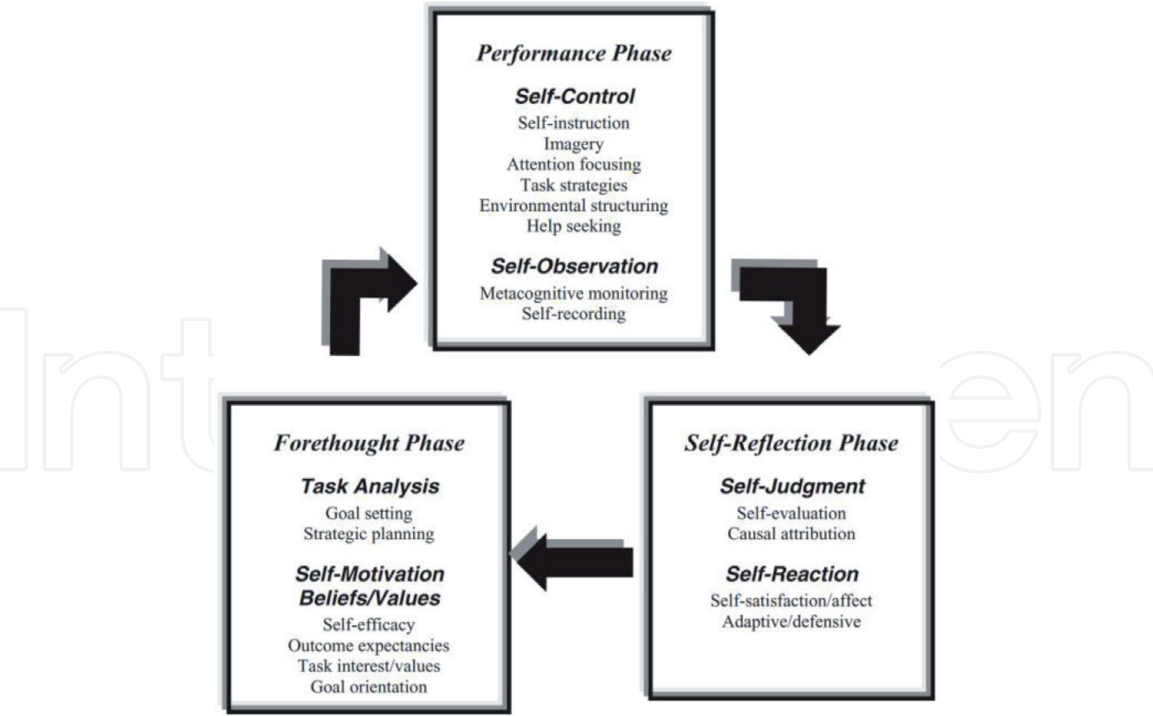
**Figure 4.**  
 Execution of model to create a training programme for a surgical skill.

The beginning of the model entails designing an instructional video, which includes the live demonstration of surgical procedures by an expert surgeon. The production of an instructional video of the master surgeon performing the procedure based on the task and subtask involved in the procedure will require the framework of multimedia instructional production [35]. In addition, the video will need the narration of the mental script produced from the methodology described in **Figure 4**. This will enable the trainee to perform mental practice and augmented with deliberate practice using low-cost practice models designed and developed by the master surgeons.

The ADDIE model is used to perform a content, task, and subtask analysis of the procedure with expert surgeons, which will aid in creating the storyboard, and designing the instructional video. For example, in tendon repair, a cognitive walkthrough is conducted with an expert surgeon, and the instructions and reflections, inclusive of kinaesthetic cues, are recorded and analysed verbatim to create a mental script validated by the master surgeon. This will be used as the narration for an expert instructional video showing the master performing the tendon repair. The instructional material – the video will then be validated by master surgeons. A low-cost practice model is needed for deliberate practice such as chicken or sheep tendon for tendon repair training. Combining the video and mental practice using the mental script allows the trainees to learn from expert surgeons anytime, anywhere, and improve with deliberate practice using the chicken/sheep practice model. Once they are ready, they are then assessed in the operating room for real-world performance to verify retention and transfer of skills in tendon repair surgery.

This new model that incorporates motor imagery and mental practice, augmented with deliberate practice, will provide an alternative training path for expert performance in surgical procedures. The tools to design and develop the instructional materials (expert instructional videos and mental scripts) with task and content analysis is founded on sound instructional design principles. It will, however, require further validation.

Current surgical training resources have been using various instructional mediums from text and multimedia materials, focusing on the step-by-step procedure



**Figure 5.**  
*Phases and sub-processes of Self-Regulated Learning (SRL).*

for performing motor tasks. These need now to be expanded to incorporate mental scripts for each standard procedure in surgery.

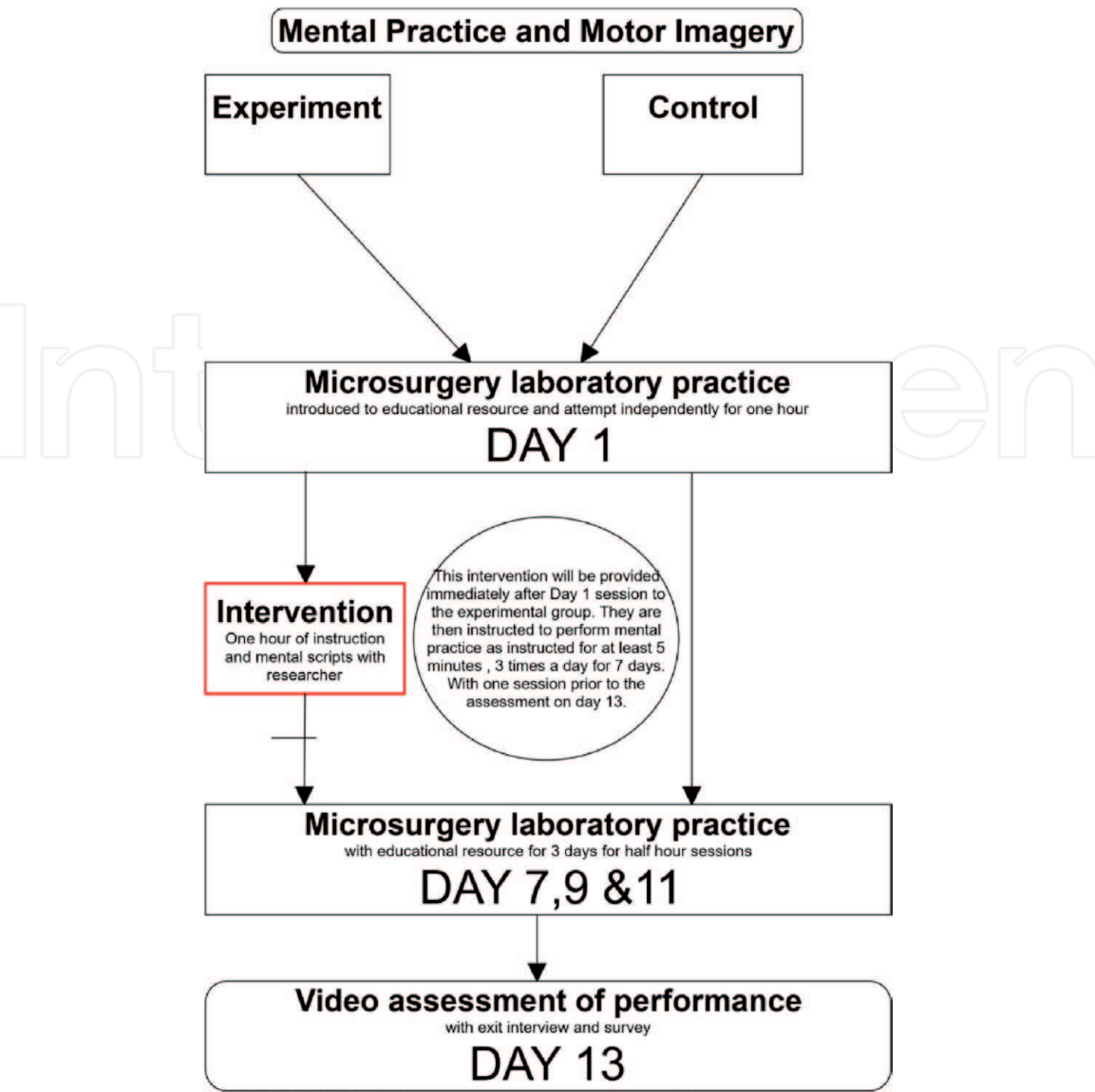
The theoretical framework for continuous learning is self-regulated learning (SRL) (**Figure 5**). SRL perceives learning as “an activity that students do for themselves in a proactive way”. It is a process by which the learner plans, monitors, and evaluates his learning to achieve learning objectives based on his developed strategies [39].

This model and tool that we proposed was executed in a study that used the design and development research framework dedicated to creating new knowledge and validating existing practice in instructional design. In this case study we aimed to demonstrate how to design, develop, and evaluate an online instructional module on micro suturing guided by Mayer’s multimedia learning theory and incorporated a mental script for the mental practice of micro suturing.

#### 4. Development of the online module to teach micro suturing skills

Using the tool for surgical skill training as a guide (as seen in **Figure 4**), the key tasks for micro suturing were identified and were listed as the expected learning outcomes with clearly stated essential tasks and competency levels. An expert review panel was identified and invited to perform a think-aloud cognitive walkthrough of these key skills. We conducted content and task analysis with the results and developed a detailed mental script for micro suturing. The mental script was incorporated into the instructional materials of the online module. The development of the online module was based on the framework of multimedia learning of the surgical procedure [37]. This online module consisted of instructional videos of the expert surgeons’ live demonstration of micro suturing, with the concurrent narration of the mental script.

The participants in the experimental phase used this online module to practice. Combining the video and the mental script allowed the participants to learn from expert surgeons anytime and anywhere. In addition, this online module was augmented with deliberate practice using the low-cost rubber glove practice model.



**Figure 6.**  
*Diagram of the pilot experiment using the learning module for micro suturing.*

The online module allowed trainees to observe expert performance, followed by mental practice with motor imagery, and then deliberate practice to reach the mastery level, as summarised in the tool for developing instructional materials in **Figure 4**. The training module created was then evaluated in a pilot study using an experimental design (**Figure 6**).

### 5. Evaluation of the online module to teach micro suturing skills

To evaluate the online module, this case study used the design process in **Table 2**. It includes the evaluation on (1) the effectiveness of the module against the existing training programmes, (2) ease of use for this module, (3) the usability.

This pilot study evaluated the new training module by comparing it with reading the manual and observing the experts performing the surgery. Participants were volunteer medical students via opportunistic sampling from two medical schools in Singapore. All participants had completed an introductory suturing course and had not performed micro suturing procedures before the study. None had prior exposure to mental practice strategies in any domains. The exclusion criteria included non-consent, failure to understand and comply with new training techniques, and

Objectives	Questions	Methods	Variables	Analysis	Conclusions
To evaluate the effectiveness of this module against the existing training programmes	Does the online module provide the opportunity for authentic practice of surgical skills?	Experimental study Randomised after participant selection	Performance, effectiveness, and efficiency. SMaRT, MIQ, time taken to complete the task	Performance	Endorse module with MIMP
To evaluate the ease of learning of this module	Does the module allow for ease of learning basic micro suturing	Survey	Cognitive load (NASA-TLX)	Cognitive load (NASA-TLX)	Recommend MIMP incorporation in the program
To evaluate the usability of learning of the new module	Is the module usable in the real world	Survey	Usability attributes (SUS)	Usability analysis with SUS	Recommend use of MIMP in module

MIMP (Motor Imagery and Mental Practice); SUS (System Usability Scale); NASA-TLX (NASA Task Load Index); MIQ (Mental Imagery Questionnaire); SMaRT (Stanford Microsurgery and Resident Training Scale Instrument).

**Table 2.**  
*Research design matrix.*

failure to meet the inclusion criteria. A sample size of 11 was chosen based on previous studies and available resources for this study.

As seen in **Table 3** below, five experienced hand surgeons (more than five years in practice as consultants/specialists) were recruited via purposeful sampling as an expert for the review process. The panel was also involved in creating the mental script and developing the training module.

5.1 Analysis of key tasks

A quantitative analysis of the commonly performed procedures was conducted from a previous study [40]. The expert panel used this to determine the index procedure (micro suturing) for this research and the motor skills with various tasks

Surgeon	Age	Sex	Years of Practice
1	62	M	35
2	46	M	13
3	40	M	7
4	47	M	17
5	68	M	41
Mean	52.6		22.6
Range	40–68		7–41

**Table 3.**  
*Expert review panel demographics.*

and subtasks required to perform micro suturing [40]. For this study, the procedure of nerve grafts and repair was chosen by the expert panel as the index procedure. The basic operative motor skill required to perform this nerve repair surgery is performing micro suturing using the microscope with an 8/0 needle with a diameter of 150 microns (0.15 mm). Mental script development was done as per **Figure 4** of the conceptual framework.

5.2 Design and development of the model

A storyboard was used to create the expert video modeling artefact from the previous step. A video recording of an expert performing micro suturing in the rubber glove model was incorporated into a whole learning module. The various steps and the sequencing resulted from the analysis of the mental script, which was developed earlier, and the mental script was also used as the narration for the video [41].

5.3 Implement

The primary author used the authoring tool Rise 360 to create the e-learning module. Rise 360 is part of the Articulate suite of eLearning authoring software. The module was then exported as an eLearning object and deployed onto a Learning Management System for universal access and distribution [42]. Finally, participants in the evaluation phase were provided the link to the online module (<https://tinyurl.com/MIMPSURGERY>).

5.4 Evaluation of the pilot experiment

There were 11 participants in both the experimental and control group, with one participant dropping out in each group, leaving 10 participants per group. The control group had an average age of 23.9 years (range 22–26), with 50% male and female. The experimental group had an average age of 23.1 years (range 21–30), with 70% male and 30% female.

The time taken to complete five micro sutures in the control and experimental groups was not statistically significant ( $p = 0.77$ ). The NASA-TLX scores between the control and experimental group were also not statistically significant ( $p = 0.60$ ).

The experimental group’s overall performance was significantly higher than the control group ( $p = 0.004$ ).

Both groups had an average “good” grading for the SUS scores (**Table 4**), indicating that the online module for micro suturing has good usability.

	Control (n = 10)	Experiment (n = 10)	p-value
Average time to complete ± SD (minutes)	12.97 ± 7.11	11.85 ± 2.06	0.77
Median time to complete (minutes, range)	10.38 (range 6.50 to 29.17)	11.83 (range 9.40 to 13.92)	
SMaRT scale scores (mean ± SD)	3.9 ± 0.47	4.54 ± 0.37	0.004
NASA-TLX (mean ± SD)	61.14 ± 24.99	59.14 ± 25.63	0.60
MIQ scores (mean ± SD)	4.88 ± 1.19	5.46 ± 1.03	0.021
SUS scores (mean ± SD)	74.25 ± 13.8	71.5 ±18.0	0.68

Table 4.
 Results of the pilot study.

The Cronbach's alpha for the SUS scale for the ten questions was computed to be 0.78, indicating acceptable reliability.

Based on the MIQ scores, the experimental group scored significantly higher than the control group in the aspects of mental imagery ( $p = 0.021$ ).

## **6. Discussion**

In this chapter we have explored the theoretical basis for surgical psychomotor skill development. We describe a model based on the educational theories and a tool to facilitate production of instructional resources and activities for this. We describe a study to evaluate the product created from the tool for its effectiveness in developing skills in a group of novices. It has shown that using a Design and Development Research approach and using the ADDIE model, subject matter experts can design and develop authentic and validated learning materials for motor skills training. We document the methodology to produce evidence-based instructional videos for surgery. This chapter elaborates on the processes involved in the creation of these learning resources, the use of specific protocols to understand the key components of a psychomotor skill from the experts; the use of the verbal protocol, and the hierarchical task analysis and its use to create a mental script to aid in the acquisition of surgical skills by the trainees. The findings of this study demonstrate the need for a new medium of instructional materials to be developed in the key and index clinical procedures in all the medical specialties requiring procedural skills. Incorporating detailed mental scripts for the surgical procedures and the methodologies to produce them need to be developed among faculty members. Most faculty members should be able to produce short, high-quality educational videos using the process described in this study. This will allow for motor imagery and mental practice to be practised by all surgical trainees to facilitate mastery in the current environment of reduced practice and motor skill learning opportunities. Deliberate practice is now universally accepted as one of the strategies for the expert performance of motor skills and has been proven effective in surgical training.

Faculty members need to be familiar with the methodology of creating mental scripts and the use of instructional design models to create multimedia instructional materials inclusive of the instructional videos by experts. The implication is for medical educators to apply instructional design and technology models to guide education curricula development. As the model described in this research and the process of creating the instructional materials and activities are translatable to other health professional education that requires the acquisition of motor skills, the findings of this research can therefore be adapted for use in other disciplines. The recommended strategy should incorporate mental skills training, i.e., the motor imagery and mental practice for the learners, and the faculty development programme for all health professionals. The faculty must be trained in the design and development of instructional videos and mental scripts. Every index procedure in surgical skill training should have the following:

1. Expert instructional video of the procedure
2. A mental script incorporating kinaesthetic cues
3. Narration of the mental script incorporated into the video
4. Inexpensive and easily accessible practice models for deliberate practice.

Though the model needs further external validation, this model and its methodology and approach to developing the individual scripts for motor imagery and mental practice will redefine surgical training. Considering the constraints of obtaining the opportunity to observe, practice, and perform in a work environment and the universal lack of accessibility to the alternative high-technology medical simulators, the trainee needs a model that will allow for deliberate practice anywhere at any time.

## **7. Limitations**

The ability to imagine a motor task and generate that mental image and maintain it while doing deliberate practice was difficult to assess. The use of the motor imagery questionnaire (MIQ) to measure this ability was simplistic. A qualitative approach, such as interview or focus group discussions with participants, would have produced much richer and more authentic data on the quality of motor imagery and the use of a focus group of experts and novices for script validation. Also, the compliance of self-directed use of the mental script for motor imagery was difficult to control and measure.

In the experimental part of the study, the main challenge was to prevent the control group from indirectly practicing motor imagery and mental practice. This was built into the study by excluding sports and musical performers in the control group [43]. The adherence of the experimental group to the instructions on mental practice before the deliberate practice sessions could not be verified. The small sample size of the participants is an obvious limiting factor, as generalizability is not possible with such a small size.

The role of confounding factors such as periods of rest before task performance, different levels of innate fine motor skills, subconscious use of motor imagery, and practice in the control group were not considered in this research. This research was confined to a laboratory and a very structured and small motor task. The generalisability of these results to more complex motor tasks has yet to be determined. This study also did not look at the other competencies required of a master surgeon, including but not confined to diagnostics and decision making, team development, and communication skills.

## **8. Conclusion**

We recommend that mental script development should be incorporated into the curriculum for faculty development. Learners should be instructed on motor imagery and mental practice techniques as part of the core skills training, like suturing and dissection. Furthermore, instructional design and technological competency should be incorporated into the curriculum for faculty development to develop instructional sound materials. Lastly, design and development research methodology should be incorporated into the faculty development programme to encourage design and developmental research in medical education research.

The case study described the methodological approach to design and develop a training module for skill acquisition for surgical training programmes, utilizing a design and developmental research framework. This study has addressed some of the challenges of surgical education and has described a model based on sound educational theories to design and develop training programmes. This will help health professional educators to design practical and relevant modules to facilitate procedural training moving forward. In summary, this study shows that

instructional materials for standardised procedures should be guided by the design and development of a mental script. The tool that has been developed and described in this research provides the methodology for this.

## **9. Practice implications**

Mental skill training for mental simulation should be incorporated into the surgical residency programme. Faculty members must be trained in the design and development of instructional videos and mental scripts. Every index procedure in procedural skill training should have the following:

1. Expert instructional video of the procedure
2. A mental script incorporating kinaesthetic cues
3. The narration of the mental script incorporated into the video
4. Inexpensive and easily accessible practice models for deliberate practice.

## **Conflict of interest**

All authors have no conflicts of interest to declare.

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