GROSS ANATOMY LEARNING USING RADIOLOGICAL IMAGES (GALERI): ITS IMPACT ON FIRST-YEAR MEDICAL STUDENTS' COMPREHENSION, ENGAGEMENT, AND COGNITIVE LOAD

BY

DR. NUR ATIQAH BINTI SA'HARI @ RAMLI

DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN CLINICAL ANATOMY

UNIVERSITI SAINS MALAYSIA

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LIST OF ABBREVIATIONS

3D	Three-dimensional
AACSB	Association to Advance Collegiate School of Business
ADDIE	Analysis, Design, Development, Implementation, Evaluation
AR	Augmented reality
BESS	Burch Engagement Survey for Students
CFA	Confirmatory factor analysis
CL	Cognitive load
CLS	Cognitive Load Scale
CLT	Cognitive load theory
COVID-19	Coronavirus disease 2019
CT	Computed tomography
e-learning	Electronic learning
e-mail	Electronic mail
ELED	E-learning Engagement Design
GALERI	Gross Anatomy Learning Using Radiological Images
Gen-Z	Generation Z
HUSM	Hospital Universiti Sains Malaysia
ICT	Information and communications technology
ID	Identification
IDOL	Instructional design for online learning
JEPeM	Human Research Ethics Committee of USM
LMS	Learning management system
MCO	Movement control order
MD	Doctor of Medicine
MOOC	Massive open online course
MRI	Magnetic resonance imaging
OSPE	Objective structured practical examinations
SPSS	Statistical Package for Social Science
USM	Universiti Sains Malaysia
VR	Virtual reality
WHO	World Health Organisation

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PEMBELAJARAN ANATOMI MENGGUNAKAN IMEJ RADIOLOGI (GALERI): IMPAK KEPADA KEFAHAMAN, PENGLIBATAN DAN BEBAN KOGNITIF DALAM KALANGAN PELAJAR PERUBATAN TAHUN SATU

ABSTRAK

Pengenalan: Pengetahuan anatomi yang baik merupakan asas kepada amalan klinikal yang selamat. Namun, waktu pengajaran yang terhad dan sifat semulajadi subjek anatomi yang padat dengan maklumat membuatkan pelajar perubatan cenderung untuk mempelajari anatomi menggunakan pendekatan hafalan. Akibatnya, maklumat tersebut tidak disimpan dalam memori jangka panjang, seterusnya menyebabkan kesukaran untuk mereka mengingat semula maklumat tersebut ketika menjalani latihan klinikal. Pandemik Koronavirus-19 juga menyebabkan kurangnya pendedahan terhadap pembelajaran kinestetik semasa kelas anatomi dan situasi ini menjadikan proses pembelajaran kurang menarik. Pelajar perubatan merasakan bahawa pembelajaran anatomi adalah lebih menarik dan berkesan sekiranya dijalankan dalam konteks klinikal. Pada masa ini, radiologi merupakan konteks klinikal yang biasa diterapkan dalam subjek ini. Melihat akan potensinya untuk menambahbaik pembelajaran anatomi, kesan penggunaan imej radiologi ke atas pembelajaran pelajar perlu diterokai dengan lebih lanjut.

Objektif: Kajian ini bertujuan untuk mengkaji impak kursus e-pembelajaran Anatomi Menggunakan Imej Radiologi (GALERI) kepada pembelajaran anatomi dalam kalangan pelajar perubatan tahun satu, Universiti Sains Malaysia.

Metodologi: Dua kursus e-pembelajaran tambahan untuk pembelajaran anatomi direka berdasarkan kerangka Reka Bentuk Penglibatan dalam E-pembelajaran (ELED): (i) e-pembelajaran anatomi menggunakan imej radiologi (GALERI), dan (ii) e-pembelajaran anatomi tanpa menggunakan imej radiologi. Kesannya terhadap pembelajaran anatomi dikaji menggunakan percubaan rawak terkawal ke atas 82 orang pelajar perubatan tahun satu yang telah bersetuju untuk menyertai kajian ini. Melalui kaedah randomisasi berstrata, para peserta dibahagikan kepada dua kumpulan, iaitu kumpulan GALERI yang didedahkan kepada e-pembelajaran GALERI; dan kumpulan pengimbal yang didedahkan kepada e-pembelajaran tanpa imej radiologi. Pada hari pertama kajian, kedua-dua kumpulan menjalani penilaian pra-e-pembelajaran untuk mengukur pengetahuan asas mereka. Pada keesokan harinya, mereka diberi akses ke kursus e-pembelajaran mengikut kumpulan masing-masing. Sejurus selepas menyelesaikan kursus e-pembelajaran, semua peserta diminta untuk mengisi dua jenis soal selidik yang mengukur tahap penglibatan dan beban kognitif, diikuti dengan penilaian pasca-e-pembelajaran yang mengukur tahap pemahaman mereka setelah menamatkan kursus. Peningkatan pengetahuan mereka juga dinilai melalui perubahan markah pra- kepada pasca-e-pembelajaran. Di samping itu, maklumbalas terbuka peserta terhadap kesan e-pembelajaran ke atas pembelajaran mereka diambil. Ujian-t tidak bersandar dijalankan untuk menganalisa perbezaan markah pra- dan pasca-e-pembelajaran, skor penglibatan pelajar secara kognitif, skil dan afektif, dan skor beban kognitif antara kedua-dua kumpulan. Ujian-t bersandar digunakan untuk menganalisa perbezaan skor pra- dan pasca-e-pembelajaran dalam setiap kumpulan kajian. Ujian ANOVA berulang dijalankan untuk menganalisa peningkatan tahap pemahaman dan analisis tematik dijalankan ke atas data maklumbalas pelajar.

Keputusan: Analisa membuktikan kedua-dua kumpulan menunjukkan peningkatan yang signifikan dalam pemahaman mereka mengenai topik anatomi yang dipilih setelah menamatkan kursus e-pembelajaran. Walau bagaimanapun, tidak terdapat perbezaan yang signifikan antara kedua-dua kumpulan. Tahap penglibatan pelajar dan beban kognitif juga tidak menunjukkan perbezaan yang signifikan antara kedua-dua kumpulan. Walaupun begitu, e-pembelajaran GALERI berjaya memberi kesan positif terhadap tanggapan pelajar mengenai nilai pembelajaran, penglibatan kognitif dan penglibatan emosi.

Kesimpulan: Peningkatan skor penilaian yang signifikan menunjukkan bahawa pelajar mendapat manfaat daripada kursus e-pembelajaran yang membantu pembelajaran mereka di luar waktu pengajaran formal. Walau bagaimanapun, penggunaan imej radiologi sebagai konteks klinikal tidak terbukti mempunyai kelebihan pada pemahaman, penglibatan dan beban kognitif pelajar. Walaupun begitu, potensi imej radiologi dalam pembelajaran anatomi masih memerlukan kajian susulan dengan mengatasi batasan dalam kajian ini.

GROSS ANATOMY LEARNING USING RADIOLOGICAL IMAGES (GALERI): ITS IMPACT ON FIRST-YEAR MEDICAL STUDENTS' COMPREHENSION, ENGAGEMENT AND COGNITIVE LOAD

ABSTRACT

Background: A sound anatomy knowledge is the foundation to safe clinical practice. However, due to limited contact hours and the nature of anatomy knowledge that is packed with information, medical students tend to learn anatomy using surface-level approach. As a result, the information is not stored in the long-term memory, which would cause difficulty in retrieving the information in future practice. Furthermore, the Coronavirus disease 2019 (COVID-19) pandemic has resulted in the lack of kinaesthetic experience in anatomy learning, and thus making it less engaging. Learning anatomy in clinical context has been perceived by students to be more engaging and effective. In this imaging era, radiology has been commonly used as a context in learning anatomy. In view of its potential to improve anatomy learning, the impact of the use of radiological images as clinical context needs to be explored further.

Objective: To determine the impact of Gross Anatomy Learning Using Radiological Images (GALERI) e-learning on first-year students' gross anatomy learning in Universiti Sains Malaysia.

Method: Two types of supplementary e-learning courses on a selected anatomy topic were developed based on ELED framework: (i) Gross Anatomy Learning Using Radiological Images (GALERI), and (ii) control e-learning using non-radiological images. Their impact on gross anatomy learning was studied in a randomised controlled trial conducted on 82 consented first-year medical students. By applying the stratified randomisation method, the participants were divided into two groups, namely GALERI group and control group. The GALERI group was assigned to complete GALERI e-learning, whilst the control group was assigned to attend to the control e-learning. On Day-1 of intervention, participants in both groups were given a pre-e-learning assessment to measure their baseline knowledge. On the next day, they were given the access to the assigned e-learning course according to their respective group. Immediately after completing the e-learning course, all participants were required to fill in two questionnaires to measure their engagement level and cognitive load. Then, the participants were given post-e-learning assessment to evaluate their knowledge acquisition after completing the course. The improvement in their knowledge acquisition was calculated from the difference in the pre- and post-e-learning assessments. In addition, the participants were invited give an open feedback on the experience of using the e-learning courses in their anatomy learning. Independent t-test was conducted to analyse the difference of pre- and post-e-learning assessment scores, engagement score and cognitive load score between the two groups. Paired t-test was used to analyse the change in pre- and post-e-learning scores within each group. Repeated measure ANOVA was performed to analyse the improvement in knowledge acquisition and thematic analysis was conducted to interpret the open feedback data.

Results: The analysis showed that there was no significant difference in the pre- and post-e-learning scores between the two groups. Both groups showed significant improvement in their comprehension of the selected anatomy topic after completing the e-learning courses. The students' engagement and cognitive load level were also not significantly different between the two groups. Nevertheless, GALERI e-learning has managed to have positive impact on students' perceived value of learning, cognitive engagement, and emotional engagement.

Conclusion: The significant improvement in assessment scores highlights that students benefited greatly from e-learning course that supplement their learning beyond contact hours. However, the use of radiological images as clinical context was not proven to have an advantage on students' comprehension, engagement and cognitive load. Nevertheless, the potential of radiological images in anatomy learning can be explored further by overcoming the limitations in this study.

CHAPTER 1

INTRODUCTION

1.1 Title

Gross Anatomy Learning Using Radiological Images (GALERI): Its Impact on First-Year Medical Students' Comprehension, Engagement, and Cognitive Load.

1.2 Background of the study

Anatomy is a field in medical science which studies the human body structures. In medical curriculum, anatomy is the foundation of clinical knowledge as considerable comprehension of this subject is central to safe clinical practice. However, anatomy is often perceived as a difficult subject by medical students (Kramer & Soley, 2002; Anand *et al.*, 2004; Gunderman & Wilson, 2005; Khan *et al.*, 2015; Lieu *et al.*, 2018). Besides being content-laden and dull, the subject requires learners to have good three-dimensional (3D) visualisation and visuospatial ability – skills that are slowly acquired over time (Kramer & Soley, 2002; Lieu *et al.*, 2018; Hadie *et al.*, 2019; Rajprasath *et al.*, 2020). Disproportionately, the contact hours for anatomy teaching in medical curriculum is limited. Hence, medical students need to cram all the anatomy information along with other basic sciences subjects within a relatively short period of time (Weurlander *et al.*, 2016). This condition could reduce their motivation and interest in learning the subject, and consequently disengaged them from the learning activities. A study by Bergman *et al.* (2013) reported that the majority of medical students learned anatomy through surface-level approach, such as by practising rote learning (i.e. a memorisation technique based on repetition). This form of learning approach does not contribute to long-term knowledge retention, and thus, resulting in failure to recall anatomy knowledge during their clinical attachment and internship (Kramer & Soley, 2002; Bergman *et al.*, 2013; Amin & Iqbal, 2019).

Unsurprisingly, clinicians around the world have consensually expressed their concerns in the decline of anatomical knowledge among the medical graduates (Cottam, 1999; McKeown *et al.*, 2003; Moxham & Plaisant, 2007; Singh *et al.*, 2015; Estai & Bunt, 2016; Hall *et al.*, 2018; O'Keeffe *et al.*, 2019; Tayyem *et al.*, 2019; Kumar & Singh, 2020). This situation is one of the causes to the rising number of medico-legal litigations against the junior doctors (Yammine, 2014). The problem worsens when the suboptimal level of foundational anatomy knowledge disenable the junior doctors to explain the basis of failure cases and defend themselves against these litigations (Kumar & Singh, 2020).

Many studies had designed instructional materials to aid the comprehension of anatomy knowledge and mastery of anatomy related competencies among the undergraduate medical students. These instructional materials are achieved through multimodal teaching strategies such as lectures, cadaveric dissections, 3D models use, and computer-based learning. Furthermore, anatomy teaching is commonly conducted via different approaches that utilise educational principles and theories (e.g. blended learning, flipped classroom, team-based learning, and cognitive load theory-based) (Kumar *et al.*, 2016; Lochner *et al.*, 2016; Fallavollita, 2017; Darras *et al.*, 2018; Guy *et al.*, 2018; Siti Nurma Hanim Hadie *et al.*, 2018; Rajprasath *et al.*, 2020) However, no single method has been proven to be superior than another (Estai & Bunt, 2016; Peeler *et al.*, 2018; Amin & Iqbal, 2019).

In addition to multimodality and multi-approach in teaching, various studies highlighted the importance of contextualised learning environment in anatomy teaching, as anatomy instructions will be more effective if it is taught in clinical context (Smith & Mathias, 2011; Bergman *et al.*, 2013; Leveritt *et al.*, 2016; Bandyopadhyay & Biswas, 2017; Kumar & Singh, 2020). Common clinical contexts integrated into anatomy teaching are classified into four categories namely clinical skills, pathology, radiology and surgical procedures (Bergman *et al.*, 2011). Nevertheless, with the advancements in radiological imaging technology, medical schools have been improvising their anatomy curriculum by incorporating radiology education into their scope of teaching. It was evident that the integration of radiological imaging alongside didactic lectures, cadaveric dissection, and case-based scenarios in pre-clinical years showed positive outcomes (Buenting *et al.*, 2016; Kumar *et al.*, 2016; Gaetke-Udager *et al.*, 2018; Marsland *et al.*, 2018a; Peeler *et al.*, 2018). Despite encouraging outcomes, a substantial amount of publications highlighted the insufficient integration of radiology in undergraduate medical education (Schober *et al.*, 2014; Dmytriw *et al.*, 2015; Sadler *et al.*, 2018; Bell *et al.*, 2019; Glenn-Cox *et al.*, 2019; O'Keeffe *et al.*, 2019)

In Universiti Sains Malaysia (USM), anatomy is taught mainly in the first two years of the five-years undergraduate medical programme. The content is delivered mainly via lecture and non-dissection practical sessions. In line with the current trend of blended learning, USM anatomy faculty is starting to use electronic learning (e-learning) modules to further consolidate learning. Radiology has also been vertically integrated into the pre-clinical year curriculum but in minimal amount. Therefore, the faculty is still in the process of formulating a curriculum that is effective in enhancing comprehension of the topic, promote self-learning amongst students of current generation and eventually produce competent medical graduates.

1.3 Justification of the study

This study designed a supplementary e-learning course that can help the pre-clinical year students to understand gross anatomy better. The pre-clinical phase of medical curriculum is a critical period to lay the foundation of medical knowledge. Therefore, it is crucial for the pre-clinical year medical students to master the basic sciences knowledge, especially anatomy before moving on to apply the knowledge in clinical phase. However, learning anatomy is often challenging for the students as there are extensive amount of anatomical input that need to be covered within limited schedule period. Hence, it is important for lecturers to design a learning platform that can help the students to do self-revision at their own pace. E-learning was chosen as the delivery medium to allow students to have more control of their learning (Regmi & Jones, 2020). In addition, due to the unpredictable progression of Coronavirus disease 2019 (COVID-19) pandemic, e-learning is the most viable medium as it allows students to access the content remotely and maintain social distancing.

Moreover, this study incorporated radiological images into the e-learning content. The incorporation of radiological images was to employ the idea of vertical integration which has been proven to increase students' motivation (Bergman *et al.*, 2013). As motivation is strongly related to engagement (Özhan & Kocadere, 2020), this study measured students' cognitive, physical, and emotional engagement whilst completing the course. Simultaneously, this study will investigate the impact of adding the e-learning course on the cognitive load of the novice students. This is to ensure that this method does not impose unnecessary load on the students' cognitive capacity.

1.4 Benefit of the study

This study will allow the pre-clinical students to have a guided exploration of another pedagogy in learning anatomy. The addition of e-learning course to the current curriculum provides another opportunity to repeat retrieval of facts from lecture and practical sessions, which in turn improves the functions of the long-term memory (McKimm & Swanwick, 2009; Kumar *et al.*, 2016). The integration of radiological imaging provides the students with an early exposure to one of the common investigations used in clinical setting and this promotes vertical integration. Consequently, they will be able to appreciate the context of the application of anatomy knowledge in their future clinical practice and become more motivated to master the subject (Kumar *et al.*, 2016).

Since the formal contact hours between anatomy lecturers and students in lecture and practical sessions are limited, the supplementary e-learning course containing activities and formative assessment helps the lecturers to identify students learning needs and enable them to support the students' learning better. The use of radiological imaging makes the subject more interesting as it adds to the variety of approach to teach anatomy.

Finally, if the result of this study is constructive, it will provide objective evidence for the faculty to implement this pedagogy into current pre-clinical curriculum which makes it more holistic in order to produce competent future doctors.

1.5 General objective

To determine the impact of 'Gross Anatomy Learning Using Radiological Images' (GALERI) e-learning on students' gross anatomy learning.

1.6 Specific objectives

1. To investigate the students' knowledge comprehension by:
    a) determining the difference of assessment scores between GALERI and control groups.
    b) determining the change in assessment scores within GALERI and control groups.
    c) investigating the interaction effect between types of e-learning and time points of assessment on students' comprehension.
2. To investigate the students' engagement level by determining the difference of
    a) cognitive engagement score between GALERI and control groups.
    b) physical engagement score between GALERI and control groups.
    c) emotional engagement score between GALERI and control groups.
3. To investigate the students' cognitive load by determining the difference of:
    a) intrinsic load score between GALERI and control groups.
    b) extraneous load score between GALERI and control groups.
    c) self-perceived learning between GALERI and control groups.
4. To explore students' experience learning anatomy through e-learning platform in both groups.

1.7 Research questions

1. a) Is there any difference in the pre-e-learning assessment scores between GALERI and control groups?

   b) Is there any difference in the post-e-learning assessment scores between GALERI and control groups?

   c) Is there any interaction effect between the types of e-learning and time points of assessment on students' knowledge comprehension?

2. Are there any differences in students' cognitive, physical, and emotional engagement levels between GALERI and control groups?
3. Are there any differences in students' intrinsic load, extraneous load, and self-perceived learning scores between GALERI and control groups?
4. How would students describe their experience attending the allocated e-learning session?

1.8 Research hypothesis

1. a) (i) There is no difference between the pre-e-learning assessment scores of GALERI and control groups.

   (ii) The post-e-learning assessment score of the GALERI group is higher than that of the control group.

   b) The change of the assessment score of GALERI group is higher than that of the control group.

c) There is interaction effect between the types of e-learning and time points of assessment on students' knowledge comprehension.

2. a) The students' cognitive engagement level in GALERI group is higher than that of control group.

   b) The students' physical engagement level in GALERI group is higher than that of control group.

   c) The students' emotional engagement level in GALERI group is higher than that of control group.

3. a) The students' intrinsic load score in GALERI group is lower than that of control group.

   b) The students' extraneous load score in GALERI group is lower than that of control group.

   c) The students' self-perceived learning score in GALERI group is higher than that of control group.

1.9 Operational definitions

Radiological Imaging: This term derives from "radiology" and "medical imaging". Radiology is one of the medical specialties that deals with radiant energy to diagnose and treat diseases by using imaging technologies. Medical imaging includes different imaging modalities and processes to image the human body for diagnostic and treatment purposes (*WHO|Medical imaging*, 2017). In this study, radiological imaging refers to x-rays (radiographs), computed tomography (CT) scan images, and magnetic resonance imaging (MRI) images that portray the normal anatomical structure of the thigh.

E-learning: E-learning has been defined as an educational method that assists learning by the utilization of information and communications technology (ICT) to create an opportunity for learners to have access to all the required educational programs (Golband *et al.*, 2014). In this study, e-learning refers to an online course in OpenLearning platform that the research team has customised to suit the learning outcomes of the selected anatomy topic.

Comprehension: Comprehension is when a student is able to (i) translate information into other terms, language, or other forms of communication, (ii) interpret the information by reorganising the idea into a new composition in their mind, and (iii) extrapolate future events or consequences based on that information (Bloom *et al.*, 1956)**.** In this study, comprehension of gross anatomy of the thigh will be demonstrated by the students through the difference in their pre- and post-e-learning assessment scores.

Cognitive engagement: It is defined as the intentional and actively focused awareness of one's tasks, objectives, or activities that is indicated by willingly giving one's attention to and having optimistic thoughts about one's work, with the purpose of improving effectiveness at those tasks, objectives, or activities (Kuok & Taormina, 2017). In this study, it refers to the focus and attention invested by the students whilst completing the supplementary e-learning course.

Physical engagement: It is defined as the bodily involvement in tasks, objectives, or activities by willingly investing one's energy and effort to perform and complete those tasks, objectives or activities (Kuok & Taormina, 2017)**.** In this study, physical engagement refers to the energy and effort invested by the students to complete the supplementary e-learning course.

Emotional engagement: Emotional engagement is the willingness attachment to tasks, objectives, or activities having a positive feeling about doing and completing those tasks, objectives or activities (Kuok & Taormina, 2017). In this study, it refers to the positive feeling of enthusiasm, excitement, and pride while doing and completing the supplementary e-learning course.

Intrinsic load: This term refers to the inherent difficulty of learning contents arising from the interactivity between the principal elements in the material being learned (Kirschner, 2002; Paas, Renkl & Sweller, 2003). In this study, it refers to the complexity of the instructions presented in the supplementary e-learning course.

Extraneous load: It is defined as the unnecessary elements that interfere with the construction and storage of schema, and thus hinders learning (Paas, Renkl & Sweller, 2003). In this study, the term refers to the clarity and effectiveness of the way that the instructions been presented in the e-learning course.

Self-perceived learning: It is defined as students' perception of the extent to which the instruction has improved their understanding of the topic (Hadie & Yusoff, 2016). In this study, this term is used to refer to students' perception of how much the e-learning course had helped in enhancing their understanding of gross anatomy of the thigh.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter explicates the evolution of relation between anatomy education and radiology, the use of e-learning in anatomy education, the concept of students' knowledge comprehension, engagement and cognitive load.

2.2 Relation of anatomy education and radiology

2.2.1 Anatomy education and its evolution

Anatomy is the cornerstone for medical education, thus a good comprehension of this knowledge is essential for safe clinical practice (Bergman *et al.*, 2011; Orsbon *et al.*, 2014; Estai & Bunt, 2016; Charkhat Gorgich *et al.*, 2017; Sawant & Rizvi, 2017; Kumar & Singh, 2020). Traditionally, cadaveric dissection and didactic lectures were regarded as the gold standard methods to teach anatomy in undergraduate medical curriculum (Sugand *et al.*, 2010; Patel *et al.*, 2015; Darras *et al.*, 2018). Nevertheless, in the early 20th century, there was a major revamp in the medical education curriculum due to the cognizance of the behavioural and social aspects of medicine. This led to the horizontal and vertical integration of anatomy with other subjects, and thus resulted in significant reduction of anatomy teaching hours (Drake *et al.*, 2009; Sugand *et al.*, 2010; Arantes *et al.*, 2018). As a consequence, the content of anatomy syllabus was compressed to accommodate the change as more focus was given on the clinically relevant topics (Sbayeh *et al.*, 2016; Charkhat Gorgich *et al.*, 2017; Sawant & Rizvi, 2017).

In fact, some medical institutions are not conducting cadaveric dissection in their undergraduate medical program due to time constraint, religious belief, culture, and cost (Estai & Bunt, 2016; Habicht *et al.*, 2018). Technological advances in the 21st century have imposed significant impact on the cadaveric dissection practice in medical schools as it can be replaced with more innovative modalities such as virtual dissection and 3D printed models (Sugand *et al.*, 2010; Patel *et al.*, 2015; Darras *et al.*, 2018; Habicht *et al.*, 2018). Although it can be argued that technology-enhanced learning has successfully addressed the limitation of cadaveric dissection in medical curriculum, the role of cadaveric dissection as a teaching modality is seen as important in developing kinaesthetic learning experience and professional behaviour (Estai & Bunt, 2016; McMenamin *et al.*, 2018). Hence, a new model of cadaveric dissection — the Silent Mentor programme — that incorporates clinical integration and collaborative learning in an interprofessional health education environment was introduced (Saw, 2018; Lai *et al.*, 2019). In many Asian cultures, the use of human cadaver for dissection is considered a taboo. However, the Silent Mentor programme was created based on the principle that life's value is not extinguished by death which has changed the public's mindset towards body donation (Lai *et al.*, 2019). Instead of keeping the anonymity of the bodies, also known as the silent mentors, their names and brief histories are made known to the students and the public on university websites (Lai *et al.*, 2019). This helps the medical students to build rapport with the silent mentors and treat them as a human instead of just cold cadavers. The medical students are also required to perform a gratitude ritual during each dissection session and voluntarily attend the memorial ceremony to express their appreciation towards the silent mentors (Saw, 2018; Lai *et* *al.*, 2019). Henceforth, this programme managed to instil a sense of humanity in medical students in addition to improving their understanding of anatomical structures and clinical skills (Saw, 2018).

2.2.2 Impact of anatomy education change

In general, anatomy is usually taught during the pre-clinical phase of an undergraduate medical curriculum. Given the fact that the anatomy education syllabus is compressed in the modern integrated curriculum, there is an increasing concern among stakeholders with regards to declining anatomy knowledge of medical graduates (Yammine, 2014; Singh *et al.*, 2015; O'Keeffe *et al.*, 2019; Kumar & Singh, 2020). A survey has been conducted by Cottam *et al*. (1999) to determine the adequacy of gross anatomy knowledge among medical students upon admission to a postgraduate residency program. The survey proved that the gross anatomy knowledge in medical graduates had declined significantly compared to the medical graduates ten years prior.

Insufficient anatomy knowledge could lead to difficulty in developing and retaining clinical knowledge and skills, which consequently results in procedural and surgical errors (Bergman *et al.*, 2011). In addition, the soaring importance of radiological imaging in diagnostic medicine demand the medical graduates to be able to interpet these images correctly as formal report from the radiologists may be delayed (Marino *et al.*, 2019). As diagnostic imaging is fundamentally anatomy in two dimensions, current medical graduates must possess a solid foundation in anatomy including its normal variants to at least recognise emergency radiologic findings (Friloux *et al.*, 2003; Jack & Burbridge, 2012; Gunderman & Bedi, 2015). Many medico-legal litigations related to poor anatomical knowledge, particularly in interpreting radiographs were reported (Guly, 2001; Pinto & Brunese, 2010; Pinto *et* *al.*, 2012; Waite *et al.*, 2017, 2019). It is even more worrying if the substandard anatomy knowledge leads to the inability of these clinicians to defend themselves against these litigations (Kumar & Singh, 2020).

2.2.3 Role of anatomy knowledge in achieving radiology competency

Alarmed by the senior clinicians' concern regarding the anatomy knowledge incompetency of new medical graduates and postgraduates interns, anatomy faculties all over the world are dedicated to redesign anatomy curricula as an effort to produce more competent medical graduates (Estai & Bunt, 2016; Peeler *et al.*, 2018; Kumar & Singh, 2020). It is evident from various studies that students learn effectively in a system-based approach that applies multimodal pedagogies (Estai & Bunt, 2016; Kumar *et al.*, 2016; Peeler *et al.*, 2018).

One of the pedagogies that is commonly applied is the use of radiological imaging, such as plain radiographs, CT and MRI scans. This form of teaching is a useful complement to both cadaveric dissection-based and non-dissection-based teaching. In cadaveric dissection teaching, radiological imaging helps to improve the quality of laboratory instruction and the efficiency of student dissection time (Reeves *et al.*, 2004). For non-dissection-based pedagogies, radiological imaging allows in-vivo visualisation of anatomical structures and provides insight into the pathological conditions (Gunderman & Wilson, 2005; Schober *et al.*, 2014; Peeler *et al.*, 2018; O'Keeffe *et al.*, 2019). Therefore, the combination of radiological imaging with other anatomy teaching modalities is pertinent to compensate for the absence of cadaveric dissection in the undergraduate medical curriculum (O'Keeffe *et al.*, 2019). It has been shown that, radiological imaging, especially ultrasonographic and CT scans enhance students' appreciation of anatomical spatial relationship (Buenting *et al.*, 2016; Estai & Bunt, 2016). Phillips *et al.* (2018) has highlighted the importance of teaching spatial relationship as students need to be able to reconstruct three-dimensional structures from a series of two-dimensional radiological images in their future clinical practice. A good visuospatial ability along with a deep understanding in anatomy are considered prerequisites for clinicians particularly radiologists (Phillips *et al.*, 2018).

Besides that, learning through radiological imaging is relevant for preparing medical students for future clinical practice as they will frequently encounter the internal anatomy of the human body in the form of radiological imaging during their practice (Friloux *et al.*, 2003; Kumar *et al.*, 2016; Peeler *et al.*, 2018; O'Keeffe *et al.*, 2019). Unfortunately, concerns have been raised among medical educators with regards to inability of medical graduates to interpret simple radiographic images, which would render misdiagnosis (Christiansen *et al.*, 2014; Bell *et al.*, 2019). This issue could be due to minimal integration of radiology and anatomy teaching in the pre-clinical year, thus leaving a long gap between learning anatomy and retrieving the knowledge to apply in clinical context (Amin & Iqbal, 2019; Rajprasath *et al.*, 2020). In North America, only 7.5 hours, on average, were dedicated for radiology in pre-clinical years and it is mostly taught in correlation with anatomy and pathology (Rubin & Blackham, 2015). A survey by European Society of Radiology showed that 22% of European medical schools have a median of 59 or 66 hours for radiology teaching and the majority of this time is distributed within the clinical years (Chew *et al.*, 2020). In the UK, radiology teaching only occupies for an average of 5% of total teaching time in medical school (Heptonstall *et al.*, 2016). The most recent study by Chew *et al.* (2021) on four Scottish medical schools revealed that pre-clinical radiology teaching time ranges from only 1 to 16.6 hours. This situation highlights the importance of clinical contextualisation, particularly in radiological imaging to ensure that the pre-clinical students have meaningful learning that will promote information storage in the long-term memory (Desy *et al.*, 2018; Amin & Iqbal, 2019). Besides that, clinical contextualisation also has been proven to increase students motivation in anatomic learning (Nyhsen *et al.*, 2013; Schober *et al.*, 2014; Buenting *et al.*, 2016; Estai & Bunt, 2016; Heptonstall *et al.*, 2016; Kumar *et al.*, 2016).

Despite tremendous technology advancement in radiology, radiological imaging still cannot replace cadaveric dissection-based instruction as the gold standard simulator of anatomy education because it does not promote kinaesthetic learning — the sensory experience of tissues (Gunderman & Wilson, 2005; Estai & Bunt, 2016). In current CT scans, the modality usually used for virtual dissection is not able to distinguish two adjacent structures of the same density (e.g. small and large intestine) (Darras *et al.*, 2019). It also introduces a level of abstraction as it is a pictorial representation of human parts (Gunderman & Wilson, 2005).

2.3 Use of e-learning in anatomy education

2.3.1 Status of e-learning in anatomy education

The vast advancement of digital information technology has made it inevitable to be implemented in the tertiary education sector. E-learning is one form of digital information technologies that is commonly utilised in the delivery of educational material in higher institutions (Zafar *et al.*, 2014; Lochner *et al.*, 2016; Morton *et al.*, 2016; Salajegheh *et al.*, 2016; Singh & Min, 2017; Wentzell *et al.*, 2018; Regmi & Jones, 2020). E-learning is an educational tool that facilitates learning by employing ICT that allows learners to have access to all the stipulated educational programs at any time (Golband *et al.*, 2014). In literatures, e-learning is also referred as computer-assisted instruction, internet-based learning, multimedia learning, online learning or online education, technology-enhanced learning, virtual learning, and web-based learning (Regmi & Jones, 2020).

In anatomy education, e-learning is commonly used to either enhance face-to-face teaching through flipped classroom design or form a component of blended learning that allows educators to provide supplementary teaching materials beyond contact hours (Arantes *et al.*, 2018; Regmi & Jones, 2020). Prior to the outbreak of the COVID-19, it is considered impossible and undesirable for e-learning to totally replace the traditional teaching methods given the need for kinaesthetic experience of organs in learning anatomy (Estai & Bunt, 2016; Morton *et al.*, 2016; Reyes-Colón & Crespo-Pérez, 2018). However, the COVID-19 pandemic had forced the entire medical education to be delivered online due to the enforcement of movement control order (MCO) in many countries (Abbasi *et al.*, 2020; Yusoff *et al.*, 2020). Given the fluidity and uncertainty of the COVID-19 situation, the students may not be able to experience face-to-face learning for the whole academic year. Hence, anatomy educators are facing a tremendous challenge to ensure efficacy of anatomy teaching despite the limitations imposed by e-learning (Yusoff *et al.*, 2020).

Additionally, anatomy education continues beyond undergraduate medical training (Sugand *et al.*, 2010; Orsbon *et al.*, 2014; Schneider & Binder, 2019). An online survey conducted on the members of the Irish Faculty of Radiologists strongly agreed that anatomy is indispensable in pre-clinical education and need to be learnt in more detail during their training (O'Keeffe *et al.*, 2019). However, finding the time to revise and enrich anatomy knowledge is difficult due to the busy work schedule of trainee doctors (Schneider & Binder, 2019). Furthermore, the rapid expansion of medical knowledge can be overwhelming for these busy clinicians to keep up with (Schneider & Binder, 2019). Therefore, e-learning is the solution to these concerns as it is a faster, effective and adaptive way for the clinicians to access the vast amount of information in their limited spare time (Schneider & Binder, 2019).

2.3.2 The function of e-learning in anatomy teaching

E-learning is an invaluable tool in modern anatomy education. It can improve learning by supplementing the traditional teaching methods, especially for the topics that require more contact hours (Estai & Bunt, 2016; Reyes-Colón & Crespo-Pérez, 2018). Learning management systems (LMS) or online learning platforms allow students to access main and supplementary teaching materials, assignments, and formative as well as summative assessments in online repository or database (Golband *et al.*, 2014; Reyes-Colón & Crespo-Pérez, 2018). Some LMS or online platforms also conveniently allow teacher-student and student-student communications for immediate feedback or consultation on the material being learnt. Alternatively, students can also use social media platforms such as YouTube, Instagram, Twitter, Facebook and TikTok to find relevant additional learning material (Reyes-Colón & Crespo-Pérez, 2018).

Given the vast array of current multimedia format, educators are presented with various choices of teaching aid to create a more effective, engaging and exciting session for the students (Chen, 2016; Reyes-Colón & Crespo-Pérez, 2018; Regmi & Jones, 2020). Thus far, the ultra-modern e-learning use in anatomy education are in the form of augmented reality (AR), virtual reality (VR), rapid prototyping and 3D printing, that allow accurate 3D in-vivo visualisation of anatomical structures (Estai & Bunt, 2016; Reyes-Colón & Crespo-Pérez, 2018).

2.3.3 The efficacy of e-learning

A study by Singh & Min (2017) that compared digital gross anatomy lecture with face-to-face lecture revealed that digital lectures were more preferred by students. The learning performance of students who attended digital lecture were higher than those of face-to-face lecture, as the digital lectures could be revisited according to the students learning needs and pacing (Singh & Min, 2017). Another study proved the application of flipped classroom model that incorporates preparatory e-learning activities prior to traditional anatomy teaching has improved students' engagement, facilitated their learning process, and strengthened their long-term memory (Lochner *et al.*, 2016; Hadie *et al.*, 2019). The findings of these studies are aligned with a meta-analysis that reported modestly better learning achievement in students who were exposed to online learning than those learning the same material via face-to-face instruction; with a larger effect size is observed in blended learning (Means *et al.*, 2012). Subsequent studies showed that students found the use of e-learning in conjunction with traditional teaching methods is the most effective way to learn anatomy because the multimodality of the material delivery improves their understanding and memory retention (Jarrral & Afzal, 2016; Losco *et al.*, 2017; Zargaran *et al.*, 2020).

2.3.4 Instructional design framework for e-learning

Instructional design is a process of creating instructional materials that promotes the development of engaging learning experience and appealing acquisition of knowledge and skills (Chen, 2016). The application of an instructional design model as a guide in preparing and delivering learning material is crucial in producing a more focused and organised teaching materials (Chen, 2016).

There are many instructional design model available in education literatures, but the most commonly used design is the ADDIE model that was developed by the Center for Educational Technology at Florida State University in 1975 (Kurt, 2017). ADDIE is a five-phased model — analysis, design, development, implementation, and evaluation phases — that provides systematic guidance on instructional design with a focus on implementation and assessments (Chen, 2016; Drljača *et al.*, 2017). Despite that, this model requires a comprehensive analysis in advance, and thus hinders creativity and inspiration in view of its linearity and inflexibility (Chen, 2016; Drljača *et al.*, 2017).

Another commonly adopted instructional model for online instruction is the Gagne Nine Events of Instruction (O'Byrne *et al.*, 2008; Leow & Neo, 2014). The model is based on a nine events framework, which are (i) gaining attention, (ii) informing learners of the objective, (iii) stimulating recall of prior learning, (iv) presenting stimulus, (v) providing learning guidance, (vi) eliciting performance, (vii) providing feedback, (viii) assessing performance, and (ix) enhancing retention and transfer. Gagne (1988) developed this instructional design model as he believed that learning happens as a consequence to a series of events based on multi-store memory model by Atkinson and Shiffrin (Zhu & St.Amant, 2010).

Nonetheless, the growing interest in e-learning and its expanding role in higher institutions has sparked the need to develop an instructional design model specific for e-learning design. There are several e-learning instructional design models that were developed based on the common framework of ADDIE model (Alonso *et al.*, 2005; Siragusa *et al.*, 2007). For instance, Alonso *et al.* (2005), have proposed a new e-learning instructional design by adding two phases — execution and review — to ADDIE model. Likewise, Siragusa *et al.* (2007) proposed the Instructional Design

Model for Online Learning (IDOL) consisting of three main steps that were adopted from ADDIE model, which are analysis, strategy, and evaluation. The 24 pedagogical dimensions of IDOL accommodate diverse learners' needs, however, it needs to be accompanied by other instructional design models (Siragusa *et al.*, 2007)

One of the frameworks that had been proposed recently is the E-learning Engagement Design (ELED) model that was developed based on Lee and Jang's methodological framework for instructional design development. Lee and Jang's framework was produced after a comprehensive analysis of 20 studies on various instructional design models including the ADDIE model (Lee & Jang, 2014). ELED framework aims to facilitate instructors in producing an engaging e-learning material. The framework outlines four process phases in a continuous cycle, namely instructional needs, instructional objectives, learning environments, and summative assessment. In each procedural phase, the ELED framework incorporates feedback mechanism for improvement (Czerkawski & Lyman, 2016). As the framework specifically focuses on designing online environments to foster students' engagement, the principles of this framework will be adapted into the development of the tool in this study.

2.3.5 The advantages of e-learning

E-learning has become increasingly popular in education because of its flexibility (Reyes-Colón & Crespo-Pérez, 2018). Through e-learning instruction, learning can be paced according to the learners' needs and the materials can be accessed anytime and anywhere provided that students have a stable internet network (Schneider & Binder, 2019). Besides that, instructor would be able to diversify their teaching process by introducing various online activities that can be conducted through e-learning platform.

This creates a learning environment that provides exciting stimuli to the students, and thus, increase the level of students' engagement (Chen, 2016; Reyes-Colón & Crespo-Pérez, 2018). On top of that, e-learning materials can be easily updated depending on students' current needs. The delivery of the material can also be done rapidly and flexibly in different formats (Regmi & Jones, 2020). In contrast to face-to-face lectures where peer interaction is limited, e-learning enables interaction and communication between and amongst learners and facilitators during and after the e-learning navigation (Reyes-Colón & Crespo-Pérez, 2018). Nevertheless, e-learning should be designed systematically to ensure efficient delivery of information, which consequently leading to consolidation of knowledge (Regmi & Jones, 2020). E-learning also provides learners with a medium and space for self-assessments and application of knowledge in case-based learning (Schneider & Binder, 2019).

2.3.6 The disadvantages of e-learning

Although e-learning provides automated learning control to the learners, a systematic review on e-learning reported that there are variations in learners' motivation and expectations towards e-learning tool in accomplishing their learning needs and objectives (Regmi & Jones, 2020). For instance, the lack of motivation would render poor engagement to the learning materials and process, low self-efficacy and self-discipline, and minimal interaction with the educator and peers. Studies conducted specifically on massive open online courses (MOOC) — a form of e-learning material — revealed that up to 98% of learners did not complete their courses (Healy, 2017).

Besides that, a poorly designed e-learning may not be coherent with the learning outcomes. Nevertheless, an effective e-learning is usually time-consuming, costly, and labour-intensive (Regmi & Jones, 2020). Despite its increasing popularity, the integration of e-learning into a curriculum is not as simple as it seems. Thorough consideration and needs analysis are required to ensure no redundant information and extraneous load imposed on students that can hinder learning (Regmi & Jones, 2020). Although students these days are from Generation Z (Gen Z) who grow up with ubiquitous electronic devices and technology, educators still need to consider the minority group of students who lacks skills and knowledge in ICT (Regmi & Jones, 2020).

2.4 Students' knowledge comprehension

Each student has different learning styles (i.e. preferred sensory modality of information delivery) when it comes to learning anatomy namely visual, auditory, reading text or writing, and kinaesthetic (Husmann & O'Loughlin, 2019). The ultimate goal of students utilising one or more of these sensory modalities is to achieve reading and auditory comprehension (Zarrabi, 2017; Ferrari *et al.*, 2021; Utami, 2021). With the recent booming of multimedia learning that applies multiple modalities to deliver information, it is imperative for digital-age students to master both domains of comprehension to ensure effective learning (Rogowsky *et al.*, 2016).

Reading comprehension refers to the skill to process text, extract meaning from the text, and integrate the information with learners' prior knowledge (Burin *et al.*, 2018; Febrina *et al.*, 2019; Yurko & Protsenko, 2020; Smith *et al.*, 2021). It is a complex cognitive process that depends on multiple skills including decoding, fluency, language comprehension, metalinguistic skills, and vocabulary knowledge (Dagostino *et al.*, 2014; Tighe & Schatschneider, 2016; O'Reilly *et al.*, 2019; Smith *et al.*, 2021). With regards to the subject of anatomy, comprehension of information is more challenging, particularly to novice learners as it is full of jargons (Burleson & Olimpo, 2016; Chapman *et al.*, 2017). O'Reilly *et al.* (2019) stated that readers need to understand the meaning of 95% to 98% of the words in text to fully comprehend it. On top of that, inability to recognise important keywords in a topic would also impede comprehension (O'Reilly *et al.*, 2019).

Apart from the linguistic skills, reading comprehension also includes construction of literal and inferential meaning to the textual information (Dagostino *et al.*, 2014; Smith *et al.*, 2021). This is achieved by integrating the text with related prior knowledge stored in the long-term memory as schemata (Amadieu *et al.*, 2011; O'Reilly *et al.*, 2019; Smith *et al.*, 2021). Readers with higher amount of prior knowledge had been proven to outperform low-knowledge readers particularly in terms of inference making (Kendeou *et al.*, 2016; Elleman & Oslund, 2019; Smith *et al.*, 2021). Inference making is a process of using information acquired from reading or retrieved from existing knowledge to fill in the detail that are absent from the text (Kendeou *et al.*, 2016; Elleman & Oslund, 2019; Smith *et al.*, 2021). Inference making ability is well-recognised as one of the salient predictors of reading comprehension (Kendeou *et al.*, 2016; Elleman & Oslund, 2019; Smith *et al.*, 2021).

The integration of textual information with prior knowledge occurs in the working memory (Smith *et al.*, 2021). Therefore, working memory is also one of the salient predictors of reading comprehension (Tighe & Schatschneider, 2016; Elleman & Oslund, 2019; Smith *et al.*, 2021). Working memory is a limited short-term storage system that monitors ongoing cognitive processes and actions, draws selective attention to pertinent information and filter irrelevant ones, and relates the information with existing schema (Archibald, 2017; Smith *et al.*, 2021). The limit of working memory