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Exploring the impact of virtual patient design: Medical students' small group learning around medical error

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Stockholm 2020

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Exploring the impact of virtual patient design: Medical students' small group learning around medical error

THESIS FOR DOCTORAL DEGREE (Ph.D.)

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“If we teach today’s students as we taught yesterday’s, we rob them of tomorrow.”

John Dewey

ABSTRACT

Background: The demands on medical and healthcare practitioners are continuously changing, with new technologies, treatments and regulatory guidelines emerging each year. One such example is increased focus on the impact of medical error, which although difficult to measure is generally acknowledged to be responsible for significant numbers of patient harms each year. As a consequence, the provision of education and training must adapt to reflect this, providing learners with an updated range of skills that can meet the needs of their profession. An increase in the use of technology has been one way that educators have sought to achieve this, along with developing pedagogies and approaches such as problem-based learning which better reflect the challenges faced by medicine and healthcare professionals.

Virtual patients are interactive simulations of clinical scenarios that have been shown to be well-suited to the development of clinical reasoning skills. They have been widely used in medicine and healthcare training, although they have yet to be fully adopted across the sector. Virtual patients can vary significantly in their design and their use within activities. To date there is a lack of knowledge about the ways different design features of virtual patients can be optimally applied to benefit student learning.

Aim: The aim of this thesis is to increase knowledge of how virtual patient design impacts upon undergraduate medical student learning, particularly when targeting medical error education in small-group teaching.

Methods: The four studies in this thesis explore design features of virtual patients and how they impact upon different aspects of the student learning experience. Study I investigated the impact of including video elements within a virtual patient used to support a problem-based learning tutorial. Mixed methods were used to capture aspects of both student and tutor experiences, and a thematic analysis was undertaken to identify themes in the unstructured responses. Studies II-IV each explored different outcomes around the use of decision-making elements in virtual patients designed to develop awareness of medical errors. A series of six virtual patients were delivered to undergraduate medical students undertaking paediatric placements across six institutions as part of small-group teaching. Students were allocated to one of two virtual patient designs: a branched design that allowed students to make decisions, or a linear design which followed a pre-determined structure without scope for student decision-making. In study II, following the completion of all virtual patients, students completed a survey instrument designed to measure aspects of their motivation and learning strategies. Comparisons between the branched and linear groups were made to establish the impact of the virtual patient design. Study III used log-linear analysis to explore learner performance in a single-best answer assessment and included an additional group of students who received traditional lecture-based teaching. In the assessment, questions were categorised in one of 3 groups; directly related to decision points in the virtual patient cases, in the same area of management but relating to different decisions and options, and in the same broad area of medicine but different areas of patient management. Study IV compared the self-efficacy and other related factors between students who received the branched and linear virtual patients, and asked participants to complete a survey instrument directly after each virtual patient case. A regression analysis was performed to explore how different factors impacted upon the self-efficacy of students.

Results: In study I we identified eight distinct themes relating to the use of video elements. One theme related to levels of engagement, with some participants finding the use of video to be beneficial and others preferring text. Some participants identified that the use of video slowed the pace of the tutorial but was well suited to providing information about procedures. In study II we demonstrated that the use of linear or branched structures for virtual patients had no consistent impact upon the measures of learner motivation and learning strategies. Similarly, in study IV our findings showed that the use of a linear or branched design did not impact upon learner self-efficacy. However, in study III we showed that both virtual patient design and institution had an impact on student learning, and these were retained in our final model. A branching design for virtual patients improved student learning around the decision points in the virtual patient cases. Students performed equally well in the questions regarding the same management approaches but different decisions regardless of whether they received the linear or branched interventions, and scored higher than those that received traditional teaching. There was no difference between any of the groups in the questions that related to different areas of patient management.

Conclusions: Overall, our findings suggest that the use of a branched virtual patient design is able to improve student learning around medical error when used in small-group teaching, and is not associated with any impact on learner motivation or self-efficacy. Our studies have not provided any evidence that this learning transfers to other areas of medicine. These findings have been broadly repeated at six institutions, demonstrating that despite evidence of the strong impact of institutional culture on our results, the findings can be generalised to multiple settings. We conclude that educators should seek to design virtual patients which allow learners to rehearse key patient management decisions, supported by video in areas where this can be most beneficial, such as demonstrating procedures. These virtual patients should be embedded in broader learning activities that encourage learners to identify deeper features within the learning, with a view to transferring that learning to other areas of patient management.

Keywords: Virtual patients; Technology-enhanced learning; Medical education; Medical error.

PROLOGUE

I began working in higher education, and specifically medical education, nearly 12 years ago. My background and my interests at the time were purely those of a technologist; I had experience of programming, databases, and in particular, through my master's degree, working in virtual environments. This experience allowed me to find a position working with a team at St George's, University of London that were developing the tools and platform to deliver patient scenarios for the training of paramedics in the virtual world Second Life. Although this work was successfully delivered and the project team was recognised with innovation awards, the limitations of the technology were apparent. Feedback from students recognised the potential but made clear that the primitive features of a technology in its relative infancy risked distracting from the primary goal of delivering a focused and immersive learning experience.

While attending meetings and conferences I had the opportunity to see numerous examples of the higher education community's desire to showcase innovation by incorporating new technologies into their provision to students. Yet in many of these instances, I felt that they risked shifting the focus onto the technology and away from student learning. This is not a novel issue or an original insight; indeed, similar experiences were identified years earlier as virtual learning environments became widespread at academic institutions. The need for technology-based learning activities to be carefully constructed with pedagogy as a primary concern was articulated by Salmon in 2005.

"No VLE will ever be enough in itself to create great e-learning . . . without appropriate, well-supported and focused human intervention, good learning design or pedagogical input and the sensitive handling of the process over time by trained online tutors." (Salmon, 2005)

Standing in stark contrast was my St George's colleague's work in virtual patients, which used technology to support learning experiences that students were otherwise unable to obtain. These were simulations of patient encounters created using established web technologies, combined with the established pedagogic principles of problem-based learning to deliver a student-focused learning experience. This work was not technology-driven; indeed, the technology used to deliver the virtual patients had been superseded some six years previously. Yet the simplicity of the technology belied the sophistication and flexibility with which it allowed learning activities to be created, while also allowing educators with no technical skills to construct enough resources to cover whole curricula. It was the recognition of the power of this combination of factors that reinforced to me the importance of the field in which I now worked, that of *learning technology*, and evolved my focus from *technology* to *learning* as the principal component of that field.

Having developed an understanding that pedagogy needs to drive the use of technology in learning, I began to be drawn towards understanding how that might actually work in practice, and where the evidence to support these learning approaches came from. The needs of the healthcare workforce are constantly developing and changing to reflect differing demands in society, and the requirements of training programmes and pedagogy are thus on similarly shifting sand. Only continued research can provide the evidence required to support updated pedagogies and allow us to ensure that these developments keep pace with the speed of change in technology.

Throughout my prior career and experience, my exposure to research had been limited. When the opportunity to undertake doctoral studies at Karolinska came up, I therefore grabbed it. I believed that this represented the opportunity to close that loop of knowledge which could provide evidence and allow me to support the work that I was involved in. The fact that I hoped that by learning about research I might be able to close a loop perhaps betrays my naivety. The reality that becoming involved in research simply opens up an infinite number of new loops is perhaps the most significant aspect of its charm.

LIST OF SCIENTIFIC PAPERS

I. **Woodham LA**, Ellaway RH, Round J, Vaughan S, Poulton T, & Zary N (2015). Medical Student and Tutor Perceptions of Video Versus Text in an Interactive Online Virtual Patient for Problem-Based Learning: A Pilot Study. *Journal of Medical Internet Research*, *17*(6), e151. doi:10.2196/jmir.3922

II. **Woodham LA**, Round J, Stenfors T, Bujacz A, Karlgren K, Jivram T, Riklefs V, Poulton E, Poulton T. (2019) Virtual patients designed for training against medical error: Exploring the impact of decision-making on learner motivation. *PLOS ONE* 14(4): e0215597. doi:10.1371/journal.pone.0215597

III. Round J, **Woodham LA**, Riklefs V, Poulton T. Interactive Virtual Patients Improve Learning - Outcomes from the TAME project (*Manuscript*)

IV. **Woodham LA**, Bujacz A, Round J, Karlgren K, Stenfors T, Poulton T. The impact on learner self-efficacy of incorporating decision-making in virtual patients for medical error. (*Manuscript)*

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LIST OF ABBREVIATIONS

AMU	Astana Medical University, Kazakhstan
BSMU	Bukovinian State Medical University, Ukraine
HMU	Hanoi Medical University, Vietnam
HUMP	Hue University of Medicine and Pharmacy, Vietnam
KSMU	Karaganda State Medical University, Kazakhstan
MSLQ	Motivated Strategies for Learning Questionnaire
I-PANAS-SF	International Positive and Negative Affect Schedule Short Form
SGUL	St George’s, University of London, United Kingdom
TAME	The Training Against Medical Error project
ZSMU	Zaparozhye State Medical University, Ukraine

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1 INTRODUCTION

Virtual patients are a form of educational technology resource that have been increasingly used in medical education (Ellaway, Poulton, Smothers, & Greene, 2009). Although they have not fully been accepted in the mainstream (Ellaway, 2014), recent reviews indicate that the number of studies on virtual patients have more than doubled over the last decade (Kononowicz et al., 2019). A virtual patient is generally understood to be “an interactive computer simulation of real-life clinical scenarios for the purpose of medical training, education, or assessment” (Ellaway, Candler, Greene, & Smothers, 2006), but within this broad definition there are a range of possible design variants (Huwendiek, 2019; Huwendiek, De Leng, et al., 2009; Huwendiek, Reichert, et al., 2009).

A consistent message from reviews of the evidence in the field is that, despite increased levels of research taking place, more focus is needed on understanding how best to use virtual patient resources to maximum effect, and in particular how the different design features can be utilised to support learning (Cook & Triola, 2009; Kononowicz et al., 2019). This thesis seeks to explore the impact of key virtual patient design features on student learning, when specifically applied in the context of medical error education delivered as part of small-group teaching activities.

1.1 STUDY RATIONALE

It has been widely accepted in the research literature that medical error remains a significant cause of patient harms in clinical practice, and that earlier measures of incidences of preventable adverse events significantly underestimated the scale of the problem (Makary & Daniel, 2016). Following the publication of a 1999 Institute of Medicine report (IOM, 1999) which raised awareness of the problem numerous attempts have been made to reduce errors in practice, but these have had limited impact, due in part to a lack of resources (Pronovost, Holzmueller, Ennen, & Fox, 2011; Pronovost, Sexton, & Thompson, 2005). Some have recognised that improved training and education can minimise the incidence of error (Alberti, 2001), and in particular the incidence of those diagnostic and cognitive errors that are responsible for a substantial proportion of preventable adverse events in practice (Graber, Gordon, & Franklin, 2002).

The approaches by which education and training can most effectively address medical error have not yet been established. A central goal of simulation-based medical education is to reduce the number of errors and improve patient safety, and the ability to make errors within simulation training can represent a powerful learning experience (Ziv, Ben-David, & Ziv, 2005). Within medical education, the use of virtual patient simulations as tools suited for developing clinical reasoning has been widely investigated (Consorti, Mancuso, Nocioni, & Piccolo, 2012; Cook & Triola, 2009) but they have not yet been fully adopted in mainstream medical education (Ellaway, 2014).

There have been calls for research into virtual patients to mature and move on from asking questions such as “can virtual patients teach”, to instead focus upon how they can be used most effectively to mediate learning activities (Edelbring, 2013; Ellaway, 2014). The need for such research is particularly true of their application to error education, into which there has been little prior work. There are additional variables that we must consider when using virtual patients to develop learning activities targeting improved understanding of error; the term “virtual patient” encompasses multiple interpretations and models of learning resource, each of which impacts upon their utility for teaching specific skills and knowledge (Huwendiek, De Leng, et al., 2009; Kononowicz, Zary, Edelbring, Corral, & Hege, 2015). Similarly, there is little evidence relating to the use of virtual patients in small-group teaching sessions, with existing studies acknowledging the need for more research into this area (Ellaway, Poulton, & Jivram, 2015; Poulton et al., 2014; Woodham et al., 2017).

In order to establish whether the use of virtual patients can effectively target improved learning outcomes relating to medical error, we must attempt to understand how different aspects of virtual patient design impact upon student learning when used in medical error teaching. When developing a learning activity based around a virtual patient there are a great many design choices available to educators (Huwendiek, Reichert, et al., 2009). Without establishing evidence of good practice in this specific context, positive aspects of virtual patient design could be overlooked, along with possible negative consequences of certain design choices, resulting in sub-optimal learning taking place.

A key characteristic of the technology used to deliver virtual patients is that they can support different media in the form of text, images, video and other interactive elements. Although the use of media such as video is generally seen as being positive for learning (De Leng, Dolmans, van de Wiel, Muijtjens, & van der Vleuten, 2007), there is some evidence that when used in an unsuitable context it can have a negative impact on learner outcomes (Basu Roy & McMahon, 2012). Similarly, decisions are required to be made when designing the structure of a virtual patient; they can be structured in a linear fashion or include branched decision-making elements in a branched pathway design (Huwendiek, De Leng, et al., 2009). Virtual patients which include decision-making elements allow learners to make patient management choices, selecting alternative pathways and influencing the narrative of the patient case through the consequences of these choices. The inclusion of decision-making elements and the ability to make errors safely is generally held to be valuable in developing clinical reasoning skills (Bateman, Allen, Samani, Kidd, & Davies, 2013; Cook & Triola, 2009; Posel, Mcgee, & Fleiszer, 2015), but the impact of these elements needs to be explored when used in new contexts such as medical error.

Only by understanding the impact upon learners of using these design elements within the specific context of teaching medical error can we design teaching and learning activities for maximum effect, and ultimately contribute to a reduction in preventable adverse events in clinical practice. There have been repeated calls in the research literature for more research in how to most effectively design virtual patient resources and activities, particularly across a range of centres and contexts (Consorti et al., 2012; Cook & Triola, 2009; Edelbring, 2013; Huwendiek, 2019; Kononowicz et al., 2019). A failure to develop this understanding will result in the provision of poorly designed learning activities, and ultimately sub-optimal learning experiences for students and trainees in the health professions.

1.2 OUTLINE OF THE THESIS

The purpose of this thesis is to better understand the impact of virtual patient design features on student learning. Specifically, it will consider the inclusion of video and decision-making features. Recognising that the impact of these features will be dependent upon the educational setting, the focus here is on small group learning, and in particular in the context of learning about medical errors.

Chapter 2 provides a background to virtual patients and the current state of research into their design and use in teaching. It also provides detail about the current state of medical error teaching and the motivations behind this. Chapter 3 sets out the aims of the thesis and the research questions, while chapter 4 considers and justifies the research methodology that was used in relation to these questions. Chapter 5 describes the component studies in the thesis, the methods used, and the ethical considerations that were involved. Ethical considerations for the studies are summarised in chapter 6. The key findings from each of the studies are summarised in chapter 7, and the discussion in chapter 8 reflects upon the impact and meaning of these findings along with the limitations of this work. Finally, the conclusions that can be drawn from this thesis will be summarised in chapter 9.

2 BACKGROUND

The demands associated with medical and healthcare education are sizeable and daunting; recent reports have identified the scope of the challenge that must be met to develop a workforce that is trained to use new digital technologies (Topol, 2019). The expanding sphere of medical knowledge and the complexity and diversity of healthcare systems require that educational programs consistently evolve to maintain their value and relevance in the midst of shifting requirements (Cook, 2010b). Yet some contend that the fundamental techniques for educating medical practitioners do not reflect this need for evolution and have remained resolutely unchanged. This represents a significant problem for learners who have to demonstrate competence in and knowledge of a greater variety of skills and information, and to continue to update their skills throughout their working life (Prober & Heath, 2012). In order to facilitate this more efficient methods of learning are required, but research is needed to establish what these approaches may be.

One approach taken to address these challenges is to make increased use of technology to support learning, reflecting new developments in technological capability and connectivity and the increase in both the ubiquity and availability of technology and devices (Ellaway & Masters, 2008; Sandars, 2012). However, the use of eLearning has often been subject to a great deal of hype, offering a promise to solve problems upon which it cannot adequately deliver (Sandars, 2011). Nevertheless, when applied appropriately it has the potential to greatly enhance the educational experience (Cook & Triola, 2014).

2.1 MEDICAL EDUCATION

It can be argued that as the medical profession has become increasingly enlightened as to the science behind its practices, the importance of the patient at the centre of healthcare has become marginalised. This has been reflected in teaching and learning practice, with the acquisition of knowledge of the basic and clinical sciences assuming paramount importance, overtaking the goal of producing doctors with the ability to treat patients. Scientific knowledge has been abstracted from the process of healthcare, resulting in students that have a strong medical knowledge but who lack competency when applying it to real-life situations. The dangers of this have been well-recognised, with a 1993 report, *Tomorrow's Doctors*, from the UK General Medical Council (GMC, 1993) proposing curriculum change and guidance that stressed the importance of teaching knowledge, skills and attitudes for medical students in equal measure. By including attitudes as a major component of this new teaching, the report made clear the renewed focus that was required on producing doctors with the ability to treat patients, not simply understand theoretical concepts of science.

Having been created in consultation with medical schools, *Tomorrow's Doctors* accurately reflected the direction that many schools were taking. The report considered to be a significant success, with a far-reaching impact. The emphasis of medical curricula has shifted to reflect their primary objective; training doctors to have the necessary qualities (knowledge, skills and attitudes) to be able to treat patients. Many medical schools re-structured their teaching to provide systems-based and problem-based programmes, with student assessment increasing its focus on students' understanding of attitudes and behaviours (Rubin & Franchi-Christopher, 2002). As a result of its success, new editions of the report have been published to reflect the societal, educational and technological changes that have occurred since. The 2003 report (GMC, 2003) clarifies and reinforces many of the recommendations from the earlier version with a renewed focus on an outcome-based model for student achievement and assessment. The 2009 report (GMC, 2009) took this outcomes as its basis, along with the principles outlined in *Good Medical Practice* (GMC, 2006), a report which described the duties, responsibilities and expectations for practicing doctors. *Good Medical Practice* placed the care of patients as its key focus, stating that "good doctors make the care of their patients their first concern".

2.1.1 Scenario-based learning and Problem-based Learning

At the heart of the teaching in these restructured systems-based and problem-based curricula is the concept of scenario-based learning, and the particular disciplines of problem-based and case-based learning. Scenario-based learning casts the learner in a role where they must immerse themselves in a situation or narrative, heightening their engagement and fostering an emotional reaction. Scenario-based learning activities aim to mimic the experience of patient encounters, and the effect is further enhanced when placed in a collaborative context. It is the narrative of the scenario and the emotions elicited by the story that engages the learner to the extent that their retention of knowledge is increased, making the learning "stick" (Prober & Heath, 2012). Scenarios also place scientific knowledge back in the context of the patient, removing the layer of abstraction that has separated the science from practice in the past, and encouraging learners to develop the attitudes and behaviours required to successfully apply their skills and knowledge to real-life patients.

A variety of models for scenario-based learning exist which attempt to place the learner into a role in which they can apply scientific knowledge to real-life clinical contexts. Case-based learning scenarios are short, highly structured and ideally suited for linking learner knowledge of basic clinical science to preparation for clinical practice (Thistlethwaite et al., 2012). In pre-clinical years of medicine courses problem-based learning is used extensively, an open-ended and less structured instructional approach that encourages learners to demonstrate and develop decision-making skills in the context of a patient-centred scenario (Srinivasan, Wilkes, Stevenson, Nguyen, & Slavin, 2007). Although the two techniques share similarities, case-based learning is commonly characterised as having a "guided inquiry" approach, whereas problem-based learning relies upon "open inquiry" (Srinivasan et al., 2007).

The use of problem-based learning in medical education first took off at McMaster University in Hamilton, Ontario in the late 1960s, and has been widely adopted in medical education internationally (Hillen, Scherpbier, & Wijnen, 2010; Norman, 2008). In small-groups, participants in a problem-based learning session are given a patient scenario, generally on paper, which provides details of their complaint, critical signs and symptoms. The learners are then required to use these details as triggers for discussion, seeking to find explanations or diagnoses based upon the evidence and the application of their own knowledge (Norman & Schmidt, 1992). Although the principles behind problem-based learning are well defined, the practical implementation of these varies significantly worldwide. These differences have a limiting effect on the conclusions that can be reached on the widespread efficacy of the method (Koh, Khoo, Wong, & Koh, 2008; Norman & Schmidt, 2000).

The literature provides conflicting views about the effectiveness of problem-based learning in training learners for practice. Colliver (2000) argues that there is little evidence to support the view that problem-based learning improves learner knowledge and clinical performance. Norman and Schmidt (2000) take an alternative view, arguing that while they are in agreement that the evidence does not support the view that problem-based learning increases learner knowledge, there is a significant positive effect on measures of clinical reasoning and learner satisfaction, and subsequently clinical skills.

2.1.2 Cognitive theory of multimedia learning

The possibilities for the use of technology in education have been subject to both hype and criticism, but have reached mainstream acceptance in medical education (Cook & Triola, 2014; Ellaway & Masters, 2008). The use of multimedia to aid learning has been established since the use of compact discs and physical media was commonplace (Shephard, 2001), and the accessibility of materials online has increased uptake (Masters & Ellaway, 2008). The use of online video sites such as YouTube for sourcing and sharing educational videos has been explored by many educators (Duffy, 2008; Shoufan, 2019), and the use of video in problem-based learning has also been examined with results indicating mixed findings around potential benefits and disadvantages (Balslev, de Grave, Muijtjens, & Scherpbier, 2005; Basu Roy & McMahon, 2012; Ghanchi et al., 2013).

Mayer has proposed a cognitive theory of multimedia learning which builds upon the ideas of cognitive load theory (Mayer, 2009; Moreno & Park, 2010). This theory describes two information-processing channels available to learners: an auditory channel and a visual channel. The auditory channel processes knowledge representations in the form of spoken words, and the visual channel processes written words and pictures. For learning to take place these must be cognitively processed in order to move this information from sensory memory (the eyes and ears), into working memory in which organising models can be constructed, and finally integrated into long-term memory. Both sensory memory and long-term memory are essentially unlimited, but working memory has extremely limited capacity. However, it is within the limited-capacity working memory that cognitive processing takes place.

The cognitive theory of multimedia learning shares a three-level theory of cognitive load with cognitive load theory, and considers three key cognitive processes for learning to take place

(Mayer & Moreno, 2010). *Extraneous processing* is non-essential for learning and is caused by processing information that is not relevant to the intended learning outcomes. *Essential processing* is about managing the *intrinsic* cognitive load associated with representing the material in the working memory, and cannot be influenced by the quality of the instructional design (Young, Van Merrienboer, Durning, & Ten Cate, 2014). *Generative processing* takes place as a result of managing the *germane* cognitive load, a consequence of learners organising the material and constructing models within their working memory and integrating these within their existing knowledge.

The goal of instructional designers should be to minimise extraneous processing while optimising generative processing, resulting in effective learning (Van Merrienboer & Sweller, 2010). A number of principles for achieving this have been described in the research literature (Clark & Mayer, 2011; Mayer & Moreno, 2010; Moreno & Mayer, 2010; Van Merrienboer & Sweller, 2010). Similarly, since the cognitive theory of multimedia learning describes two channels for information processing each of which has their own limited capacity independent of the other, the design of multimedia learning should present materials using a variety of media to optimise the capacity of both channels (Mayer & Moreno, 2003; Moreno & Mayer, 1999; Moreno & Mayer, 2007).

2.2 VIRTUAL PATIENTS

Technology can enhance scenario-based learning by supporting well-designed learning activities (Clark, 2013), augmenting existing scenario-based learning processes and providing the means for these processes to more closely reflect the real-life experience of treating patients. Techniques such as digital storytelling, which involve creating a story using multimedia resources, encourage learner reflection (Sandars, Murray, & Pellow, 2008) and can be combined with scenario-based activities to heighten this emotional effect. Tools such as physical and software simulations and serious games seek to revolutionise and disrupt familiar methods of learning by providing original, immersive learning experiences (De Freitas, 2006). The use of high-fidelity simulations is increasingly widespread (McGaghie, Issenberg, Petrusa, & Scalese, 2010), limited mostly by available access to these facilities. Software simulations and Serious Games have gained acceptance as legitimate tools in medical education (De Freitas, 2006). In contrast, lightweight, simple tools such as interactive virtual patients represent an evolution of existing paper-based teaching techniques, and have found footholds in medical curricula across the international education community due to their low cost and ease of creation (Poulton & Balasubramaniam, 2011).

Virtual patients have been used to support many different teaching approaches, including small groups, lectures, self-directed learning and even for assessment (Ellaway et al., 2009; Poulton & Balasubramaniam, 2011; Round, Conradi, & Poulton, 2009). Primarily web-based, they place learners within a simulated patient encounter and allow them to be active participants in a clinical situation, interpreting the information available, and making decisions based upon their own judgement and knowledge (Ellaway et al., 2006). The consequences of those decisions are subsequently demonstrated by the virtual patient, helping the learner to develop their clinical reasoning skills (Ellaway et al., 2015; Poulton et al., 2014). Learners are thus provided with a simulated version of experience in clinical practice and are able to develop their skills in a way that is safe, without mistakes causing harm to real patients. In addition to medicine, virtual patients have been used in other disciplines such as nursing (Georg & Zary, 2014) and primary care (Salminen, Zary, Björklund, Toth-Pal, & Leanderson, 2014). Virtual patients are generally web-based and can include additional components such as multimedia or multiple-choice questions, although other technologies such as mobile devices or virtual worlds have also been explored (Conradi et al., 2009).

Feedback and repetitive practice are key parts of effective simulation activities (Issenberg, 2006; Issenberg, McGaghie, Petrusa, Lee Gordon, & Scalese, 2005; McGaghie et al., 2010). Virtual patients share many of the characteristics of physical simulations and can draw upon many of the same principles as high-fidelity simulation to guide their design (Huwendiek, Reichert, et al., 2009). Being relatively low-fidelity, they have several advantages over high-fidelity simulations using mannequins; they can scale to larger numbers of concurrent users, provide repeated exposure for a wide range of clinical situations, and require less investment of time and money to set up, use and maintain. Being software-based, they also offer the potential for capturing detailed analytics that can be used to understand and enhance the learning experience (Topps & Cullen, 2019). Indeed, it has been argued that high-fidelity simulations offer little benefit over lower fidelity solutions (Norman, Dore, & Grierson, 2012). In making this argument, a distinction can be drawn between “engineering fidelity” and “psychological fidelity” (Maran & Glavin, 2003). Virtual patients have a relatively low level of engineering fidelity (i.e. the degree to which the physical characteristics of the task are represented) but can provide a high level of psychological fidelity (i.e. the degree to which skills of the task are captured by the simulation).

The wide variety of technical and environmental contexts in which scenario-based learning activities have been embedded is indicative of a wide-ranging interest and acceptance of the potential benefits associated with these techniques. Their use in both physical simulations and technology-enhanced learning has been extensive. However, the current state of knowledge on how best to apply these resources for maximum benefit to learners varies greatly. Research into the use of physical simulation activities has been extensive and well-documented, with a sufficient knowledge base that studies conducting reviews of the literature over long periods are possible (McGaghie et al., 2010). Issenberg argues that, for physical simulations, a tipping point has been reached whereby research can move beyond identifying the potential role of simulation, instead focusing on identifying the most effective uses of simulation for healthcare education (Issenberg, 2006) and essential requirements for successful implementations (Issenberg et al., 2005).

In contrast, it could be argued that research on virtual patients is only now reaching that stage of development; to date, although the potential for such tools has been widely identified, there is a gap in the current state of the knowledge about how best to target and deliver such activities for maximum benefit to learners. Much of the research in the field concludes that further work is required into the effective application of technology-enhanced scenario-based learning resources, and in particular virtual patients (Baldwin, Webb, Gainsborough, Howlett, & Inglis, 2011; Edelbring et al., 2012; Kononowicz et al., 2019; McGee & Kanter, 2011; Sandars, 2011).

2.2.1 Designing virtual patient activities

All eLearning resources and activities are to some extent designed; any technology provides both affordances (things that can be done) and constraints (things that cannot be done) which directly result from their design (Masters & Ellaway, 2008). Laurillard (2013) argues that teaching and education represent a design science, being based upon continual improvement to its practice through the application of established principles and drawing upon evidence from the work of others. Within medical education it is crucial that learning activities both reflect real-world medical practice and afford effective learning experiences (Ellaway & Masters, 2008).

The attempts of Phillips, McNaught and Kennedy (2010) to model the learning process place the learning environment as a critical component of an effective learning activity. This is particularly clear when considering activities such as problem-based learning, the success of which depends greatly upon its implementation and the practical constructs that shape it as an environment for learning (Dolmans, De Grave, Wolfhagen, & van der Vleuten, 2005). Salmon (2005) argues that the capacity for achieving learning cannot simply be ascribed to a technology, but must also consider the need for other factors such as human intervention and good learning design. Ellaway (2014) furthers this argument from an activity-theoretical viewpoint; she contends that learning is not intrinsic within virtual patients in and of themselves as technological artifacts. Instead, she suggests that research should instead focus on building educational activities around virtual patients. This is supported by the ways in which a single technological artifact can be reused in different contexts with varying degrees of effectiveness (Sandars, 2011), and the manner in which a virtual patient of one design can be reused in many different activities (Ellaway & Davies, 2011).

A recent review identified that knowledge regarding the utility of design features in virtual patients is limited and urged a greater focus on research into this area (Kononowicz et al., 2019). The term virtual patient is broadly applied and has come to describe a variety of resources with different designs and features (Kononowicz et al., 2015). Attempts have been made to evaluate the impact of design features (Bateman et al., 2013; Huwendiek et al., 2015; Huwendiek, Reichert, et al., 2009) while recognising that the context in which learners experience the virtual patient is central to the learning activity, and that any findings cannot be generalised beyond the context being studied (Edelbring, Dastmalchi, Hult, Lundberg, & Dahlgren, 2011; Huwendiek, 2019).

Huwendiek et al. proposed a virtual patient typology which sought to provide a reference point to guide research on virtual patient design features (Huwendiek, De Leng, et al., 2009). This typology identified nineteen different factors based around four categories. The general category provides a basic description of the virtual patient, including the title, language, provenance and expected study time. The educational category includes factors such as educational level, educational modes, coverage and objectives. The technical category includes details such as originating system, format, integration and dependence. The final category is instructional design, which includes six distinct factors.

The first factor is path type, which determines the navigational approach within a virtual patient. Navigation within a virtual patient activity will often follow one of two models: linear or branching (Huwendiek, De Leng, et al., 2009). Branching virtual patients, based on a decision tree structure, allow learners to make decisions at selected option points, thereby changing the narrative of a scenario (unlike linear virtual patients, in which the scenario remains unchanged regardless of the actions of the learner). Using a branched path-type allows educators to incorporate decision-making elements into their designed activities; these represent key patient-management decisions in the form of diagnoses or treatments and provide feedback in the form of a narrative that shows the consequences of those choices. The path type factor is closely linked with other factors in the typology, such as narrative use and patient focus (the balance between presenting data and telling a story), interactivity (the type and number of actions required from learners, including decisions), and feedback (what kind of feedback is received, and whether it is during the activity or at the end).

Another instructional design factor is the use of media in the resource. Virtual patients can support video, images, sound and animations as well as text. Mayer’s cognitive theory of multimedia learning seeks to explore the impact of the use of different media types on the learning experience (Mayer, 2009; Moreno & Mayer, 2007). There have been several studies on the use of video in traditional problem-based learning (Balslev, de Grave, Muijtjens, & Scherpbier, 2010; Basu Roy & McMahon, 2012; De Leng et al., 2007; Ghanchi et al., 2013), but not in the context of using virtual patients to coordinate these activities.

The final instructional design factor identified in the typology is the user modality, describing the number of users involved in an activity and the roles that those users take. Virtual patient resources can be used in different educational settings to facilitate lectures, tutorials, seminars or for self-directed learning (Poulton & Balasubramaniam, 2011). They have also been used in problem-based learning activities in small group settings (Ellaway et al., 2015; Poulton, Conradi, Kavia, Round, & Hilton, 2009; Poulton et al., 2014). Each setting impacts upon the user modality, along with further design decisions such as the sharing of roles within a group-based activity.

2.2.2 Experiential learning

Experiential learning theories describe education as a process of individual transformation, and are based upon the concept of learning from experience (Yardley, Teunissen, & Dornan, 2012). As an educational experience in which learners can safely experience the management of a simulated patient scenario, the use of virtual patients can be understood as a form of experiential learning (Kononowicz et al., 2016).

A key figure in understanding experiential learning is Kolb, who has described a four stage experiential learning theory (Kolb, 1984; Yardley et al., 2012). His experiential learning cycle starts with *concrete experience*, in which learners have the opportunity to learn by "doing"; in the context of medical education this can be either as part of a simulation or in a clinical setting. During the second stage, *reflective observation,* learners process and make sense of their experiences. The subsequent stage, *abstract conceptualisation*, takes place as learners develop their representation of that experience. It is at this stage that learners are able to transform the experience into learning and potentially apply it to other settings. Finally, the *active experimentation* stage describes the process of learners trying out and applying their learning for themselves as a result of further experiences (Yardley et al., 2012).

Virtual patients represent a means of delivering the *concrete experience* element of the learning cycle, allowing learners to experience a range of clinical simulations in a safe setting that they may not otherwise experience within their training (Cendan & Lok, 2012; Edelbring et al., 2011). The experiential learning cycle has been used successfully to guide the design of technology-enhanced learning activities (Omer, Choi, Brien, & Parry, 2017). It is therefore imperative that learning activities supported by virtual patients are designed to also support and scaffold the remaining stages of the experiential learning cycle if they are to optimise learning.

2.3 MEDICAL ERROR

Medical error has long been an area of interest to those seeking to improve patient safety, with a recent publication having identified that medical error is the third leading cause of death in the US health system (Makary & Daniel, 2016). In 1999, the US Institute of Medicine produced a report entitled "To err is human: building a safer health system" as part of the Quality of Health Care in America project (IOM, 1999). The report estimated that medical errors are responsible for 98,000 deaths in US hospitals each year. The recommendations made by the report contributed to an increase in efforts aimed at improving quality in the healthcare system (Pronovost et al., 2011).

However, progress towards this goal has been shown to be slow (Pronovost, Miller, & Wachter, 2006). Some estimates place the number of deaths in the US associated with preventable harm in hospitals at between 210,000 and 400,000 per year, with serious harm (as opposed to lethal harm resulting in fatality) significantly more common still (James, 2013). Evidence suggests that the issue has a similar impact elsewhere in countries such as the UK (Vincent, Neale, & Woloshynowych, 2001). Attempts to accurately measure the extent and impact of errors on patient safety have met with significant challenges (Pronovost et al., 2005). although mechanisms such as the Global Trigger Tool have allowed some estimations of the number of errors and their impact upon patient harms to be reached (James, 2013).

The difficulty in accurately measuring the impact of errors in today's healthcare system is in part due to the difficulties and barriers associated with physician accountability; where a "blame" culture is present, errors may go unreported (Wachter & Pronovost, 2009; Weingart, 2000). Reason (2000) identifies this as a "person" approach to error, whereas in contrast, a "system" approach to error identifies errors as consequences rather than causes and seeks to introduce systemic countermeasures to more effectively manage risk. There have been calls for medicine and healthcare to learn lessons from the aviation industry, in which more than 90% of errors are judged to be blameless (Nichols, 2005). By not assigning blame to individuals and introducing a reporting culture, errors can be more easily reviewed, learnt from and contributing factors addressed. Instruments such as checklists have been proposed for use in healthcare as a tool for decreasing human error, drawing further upon the strategies for avoidance of error used in the aviation industry (Eisen & Savel, 2009; Hales & Pronovost, 2006)

2.3.1 Types of medical error

When considering error in a wider context, Reason (1995) and Norman (2013) have identified a general classification in which human errors can be categorised. Error is defined as any deviance from patterns of behaviour generally accepted as being appropriate for a given situation, and can be broken down into "slips" and "mistakes". A slip describes a faulty execution of a correct and appropriate intended action sequence. A mistake occurs when an incorrect or inappropriate action sequence is executed (Zhang, Patel, Johnson, & Shortliffe, 2004). This may be due to a correct diagnosis or evaluation of the available information but a wrong choice of response (rule-based), an incorrect diagnosis (knowledge-based), or a memory-lapse which causes an erroneous choice to be made in goal-setting, planning or evaluation.

Several attempts to categorise medical errors have been made, addressing their causes and their outcomes. Graber, Gordon and Franklin (2002) considered errors of diagnosis by physicians and proposed three major categories of error. "No-fault errors" are caused by exceptional circumstances and atypical disease presentation, such that a correct diagnosis would not be expected with the current medical knowledge. "System errors" are caused by imperfections in the broader healthcare system, where inefficiencies in communication, allocations of responsibilities, faulty equipment or less than ideal working conditions result in an incorrect diagnosis being given. It is these system errors that were the focus of much of the drive for change in quality and patient safety since the Institute of Medicine report in 1999 (Kuhn, 2002).

The final category of error, "cognitive errors", refers to errors where the cause is inadequate knowledge or data gathering on behalf of physicians, and may include incidences of errors due to bias or faulty logic and reasoning (Graber et al., 2002). Although at an organisational level attempts to reduce error have mostly focused on system errors and improving quality through risk management and checklists (Hales & Pronovost, 2006), cognitive errors, particularly in relation to diagnosis, have been identified as meriting particular consideration when looking at ways of minimising incidences of error (Croskerry, 2003; Norman & Eva, 2010). A review by Graber, Franklin and Gordon (2005) identified a substantially higher incidence of cognitive error factors than those relating to no-fault or system errors and further noted that the cognitive contributions to error could be broken down into three groups; faulty knowledge, faulty data gathering, and faulty synthesis.

Zhang et al. (2004) have examined cognitive errors closely in the context of Reason and Norman's categorisation of "slips" and "mistakes", developing a cognitive taxonomy that can be used to describe the cognitive cause behind medical errors in practice, placing equal emphasis on those categorised as "mistakes" while acknowledging the strong focus on "slips" present in previous studies relating to healthcare. As the focus of the discourse on reducing medical error begins to focus increasingly on cognitive errors, improved educational provisions have been seen as a valuable tool to address this challenge (Alberti, 2001).

2.3.2 Clinical reasoning and minimising error

As previously noted, a review by Graber, Franklin and Gordon identified cognitive factors as being the most common contributor to errors in practice, and indicated that the majority of these are process errors rather than a result of a knowledge deficit (Graber et al., 2005; Norman & Eva, 2010). Although, a substantial level of medical knowledge is necessary for effective decision making these errors represent a failure in physician thinking and clinical reasoning (Croskerry, 2009). Teaching medical students to reason effectively requires a more involved understanding of the reasoning process and an educational approach to address that (Eva, 2005; Kassirer, 2010).

Extensive work into the process of clinical reasoning has theorised that it is a "dual process", with two distinct psychological processes at work (Norman et al., 2014). Decision making has been characterised as a balance between intuition and reasoning, known respectively as System 1 and System 2 thinking (Kahneman, 2003). System 1 is fast and unconscious in nature, primarily driven by a process of pattern recognition based upon prior experience, while System 2 is a slower, systematic approach driven by logic and the application of explicit rules (Norman et al., 2014). In the context of clinical reasoning, these can be represented as "non-analytic" and "analytic" approaches (Eva, 2005).

Medical educators have commonly focused on the "analytic" model when teaching undergraduate medical students; in this model, clinical reasoning is based upon an evaluation of the information provided (patient symptoms) and an understanding of the relationship between these symptoms and likely causes. This allows the clinician to compile a differential list of possible diagnoses, and combined with additional information such as the patient or family history, to determine the likely diagnosis based upon an analytical view of the relative probabilities of the possible underlying causes (Eva, 2005).

In contrast, the “non-analytic” approach is generally taken to be associated with greater levels of expertise; clinicians who have acquired a greater volume of experience can rely more heavily on matching patterns of patient symptoms, allowing them to make decisions more quickly and with less information (Norman et al., 2014; Sherbino et al., 2012). There has traditionally been a fear of encouraging those with less experience, such as undergraduate students and junior doctors, from adopting this approach, but evidence suggests that students begin to adopt this strategy and generate hypotheses at a very early stage of their education regardless (Eva, 2005).

There is a widespread belief that most errors of clinical reasoning in practice occur as a consequence of Type 1/non-analytic thinking (Norman et al., 2014) and that Type 2/analytic errors are rare but with more damaging repercussions (Croskerry, 2009). Some experts refute this, and trials suggest that there is no evidence that rapid, System 1 diagnoses are more prone to errors than System 2 diagnoses (Sherbino et al., 2012). The two forms of processing are not however mutually exclusive, and an additive combined model in which both analytic and non-analytic processes are used has been proposed as the optimal solution (Eva, 2005).

Virtual patients are recognised as being well-suited to the development of clinical reasoning skills (Bateman, Hariman, & Nassrally, 2012; Cook & Triola, 2009; Ellaway et al., 2015; Posel et al., 2015; Poulton et al., 2014). When considering virtual patients that have a branching path type (Huwendiek, De Leng, et al., 2009) we are able to include decision-making elements within the activity, allowing learners to make choices of the path to choose. Different paths result in different outcomes and consequences, allowing learners to develop their clinical reasoning skills in ways that are safe, structured, and rich in feedback and instruction (Ellaway et al., 2009). By providing undergraduate students with exposure to a wide range of patient scenarios to which they would not otherwise have access, learners are able to practice an analytic approach, while increasing the size of their available database of experience which can be used for a pattern-matching, non-analytic approach.

2.3.3 Approaches to error education

As has been previously noted, education and training has a significant role to play in reducing cognitive errors in clinical practice (Alberti, 2001). In the years since the report by the Institute of Medicine, significant progress has been made, although opportunities for learning from mistakes are still frequently missed and substantial gaps in clinician knowledge of error still exist (Bradley, Fischer, & Walsh, 2013; Huffman-dracht, Mcdonnell, & Guenther, 2010). There is evidence that learners in territories such as Germany and the UK are self-reporting that they have insufficient knowledge and training to deal with and avoid medical errors (Kiesewetter et al., 2014; Patey et al., 2007).

A range of approaches have been suggested and attempted. Several studies have described specific modules or teaching activities that have been developed to target training about medical error. The approaches taken vary considerably; some have taken a practical approach and focused on the factors that influence errors and the skills required to account for this

(Patey et al., 2007). Another study advocates an approach that addresses learner understanding of the underlying causes of error, focusing on decision making points, and evaluating the potential for error at each of these points to encourage an analytic, non-judgemental approach (Vaughan, Bate, & Round, 2012). Other studies have attempted to address the challenge with modules encouraging full disclosure of errors (Gunderson, Smith, Mayer, McDonald, & Centomani, 2009). Each of these studies reports some evidence that specialised error training can improve awareness amongst students. This viewpoint is supported by other studies evaluating the effect of modules designed specifically to raise awareness of error; utilising a pre/post-test design, they provide evidence of raised performance or improved self-reported awareness following completion of the module (Halbach & Sullivan, 2005; Paxton & Rubinfeld, 2010).

Simulation activities enable learners to make errors safely without risk to real-life patients, and to learn by reflecting on these. The process of making errors and reflecting upon the associated negative consequences and emotions can help learners to avoid making the same or similar mistakes in future (Ziv et al., 2005). The importance of an environment of collegiality and cooperation when acknowledging the fallibility of clinicians is at the centre of reforms of medical education suggested by Lester and Tritter (2001).

While such activities allow learners to make and learn from mistakes safely, Eva (2009) argues that educators should seek to induce error in learners as a formative learning experience. He suggests that targeted feedback when learners make errors can help them construct knowledge in ways that aid learners’ retention of knowledge and their ability to apply that knowledge to real-life circumstances. However, he also acknowledges that this process can cause discomfort to learners with an aversion to making errors.

It is this hypothesis (that by inducing learners to make errors in training we can foster improved learning) which we will explore in this thesis. Building upon the established approach of using virtual patients in small group teaching, we will examine the impact of key virtual patient design features (media and path type) upon student learning. We will use the decision-making functionality of virtual patients to provide the opportunity for learners to make errors safely. Taking a holistic view of the learning process we will then not only measure the outcomes in terms of improved learning but also examine the positive and negative aspects to the resulting learning experience. Our goal will be to develop an improved understanding of how we can effectively design virtual patient activities to support an improved learning experience around medical error.

3 AIMS AND RESEARCH QUESTIONS

The aim of this thesis was to develop an improved understanding of how virtual patient design impacts upon undergraduate medical student learning when targeting medical error education.

A small group setting was used for all interventions. In this setting the specific objectives were to explore undergraduate student learning with virtual patients in relation to the following elements:

- Student perceptions of the inclusion of video elements when compared with text – addressed in study I
- The effect of the inclusion of decision-making elements on
    - Learner motivation and learning strategies – addressed in study II
    - Learner performance and transferability of learning – addressed in study III
    - Learner perceptions of the educational activity and their resulting self-efficacy – addressed in study IV

3.1 RESEARCH QUESTIONS

The overarching research question for the project was: How can virtual patients be designed to support student learning around medical error?

The specific research questions explored in the individual studies were:

- How do undergraduate medical students interpret and evaluate information provided by video, when compared with text, presented in the context of a branched interactive online virtual patient designed for small group teaching? (Study I)
- Do the motivation and learning strategies of undergraduate medical students at participating institutions differ when given error virtual patient learning scenarios that contained or did not contain decision-making elements? (Study II)
- Does the inclusion of decision-making elements within virtual patients impact upon learner performance and the transferability of learning to other settings? (Study III)
- How does the inclusion of decision-making elements in virtual patients designed for medical error education in a group setting impact upon undergraduate learners' perceptions of the educational activity and their resulting self-efficacy? (Study IV)

4 RESEARCH APPROACH

4.1 PHILOSOPHICAL POSITIONING

Different assumptions of knowledge, learning and reality can, and many believe should, have a fundamental impact on any research study. There is an increasing demand for medical education researchers to make explicit the theoretical perspective which frames their research (Bunniss & Kelly, 2010) so that this can be considered by others when critically evaluating their findings. The theoretical perspective of a researcher is informed by three key questions; the ontological question (what is the nature of reality), the epistemological question (what is the nature of knowledge, i.e. what can be known) and finally the methodological question (what is the nature of research, and how can the researcher find out what they intend to know) (Guba & Lincoln, 1994).

Medical education research has historically been dominated by the positivist paradigm in which much medical and healthcare research is conducted (Illing, 2013). This viewpoint is predicated on an ontology of realism, the idea that there is a single knowable reality that is absolute, and the epistemological viewpoint that this reality can be objectively identified in such a way that it is not filtered through the viewpoint of the researcher. This paradigm tends to be investigated using quantitative methods such as experiments and surveys, which aim to provide evidence to prove a distinct hypothesis. A range of other paradigms are also widely used which are either complementary and share certain characteristics with positivism (e.g. post-positivism, grounded theory) or are contradictory (e.g. constructivism). A constructivist viewpoint contends that reality is relative (a relativist ontology) with multiple realities that are based upon different experiences, and that leads to an epistemological position that knowledge is constructed subjectively, reflecting the interaction between the researcher and the study participants. Exploring research from this perspective motivates a more qualitative approach.

As a researcher I am approaching the questions in these studies from a post-positivist perspective. Post-positivism assumes a critical realist ontology, in which an absolute reality does exist, but is complex and impossible to know. Epistemologically, post-positivism is objectivist, aiming at objectivity while accepting that this cannot be fully achieved (Guba & Lincoln, 1994).

4.2 POSITIONING THE RESEARCH STUDY

The aim of the studies in this project is to explore the impact of virtual patient design features upon student learning from a post-positivist perspective. Since no two student perspectives on learning will be identical, all learners may respond differently to an intervention and other factors such as culture, levels of experience etc. may have an impact. Such confounders are nearly impossible to avoid in experimental education research, and must be carefully considered when designing comparisons of educational interventions (Cook, 2009). A clear example of such confounders can be seen in the multi-centre nature of studies II-IV in this project, in which the institution in which a participant is enrolled was expected to have a significant impact for several reasons; examples include the level of acceptance of problem-based learning as a pedagogical approach, the quality and approach to tutoring and facilitation, and the cultural approach to error as being no-blame and a learning opportunity. These confounding factors cannot easily be controlled, so in our analysis we are seeking to demonstrate that findings can be repeated across institutions regardless of the influence of any confounding factors.

Cook, Bordage and Schmidt (2008) proposed a framework for classifying the purpose of research into 3 categories. *Description* studies are based upon observation, and primarily serve to report upon some form of intervention or process. *Justification* studies typically focus upon the question of whether an intervention works and demonstrate this by means of a comparison. *Clarification* studies in contrast seek to identify how or why an intervention might work and may build upon models and theories to develop and test hypotheses.

In this project study III falls into the category of *justification*, as it attempts to measure learner performance in the area of learning being targeted; that is, the study asks the question 'does it work'? However, studies I, II and IV fall into the category of *clarification*, as they seek to better understand why an intervention might work, although they do so using differing methods.

4.3 RESEARCH DESIGN AND ISSUES OF BIAS

The nature of the research questions being asked is the primary determinant of the research methods used in the project. Having determined a broad approach based upon the type of question being asked, practical considerations such as access to participants, ethical considerations, and availability of resources also informed the research approach taken.

In study I, the research question asks *how* students interpret the information provided by video compared with text. This study falls into the *clarification* category and motivates a study design that contains qualitative inquiry. Ultimately, and in keeping with the post-positivist theoretical perspective being taken, the need for data collection to take place as part of a curriculum level intervention indicated that a mixed-methods approach was suitable. A convergent parallel study design (Creswell & Clark, 2010) was adopted that allowed multiple sources of data, both qualitative and quantitative in nature, to be triangulated to arrive at the study findings. Given the use of qualitative methods, it is critical that consideration be given to the *reflexivity* of the researchers i.e. their roles and characteristics, and how that might impact upon their perspectives and assumptions to influence data collection and interpretation (O'Brien, Harris, Beckman, Reed, & Cook, 2014). Guidelines for reporting qualitative research are designed to allow readers to adequately evaluate the reflexivity of authors and issues of bias (O'Brien et al., 2014; Tong, Sainsbury, & Craig, 2007).

Studies II-IV share a common structure and participants, but a variety of instruments were used to address different outcome measures in order to provide a holistic view of the learning process which occurred. We explored the impact of technological interventions on learning performance (representative of a *justification* study), but also on learner motivation, learning strategies and self-efficacy as key indicators of the nature of the learning experience. In examining these concepts, we were attempting to better understand the nature of the learning experience, and thus these represented *clarification* studies.

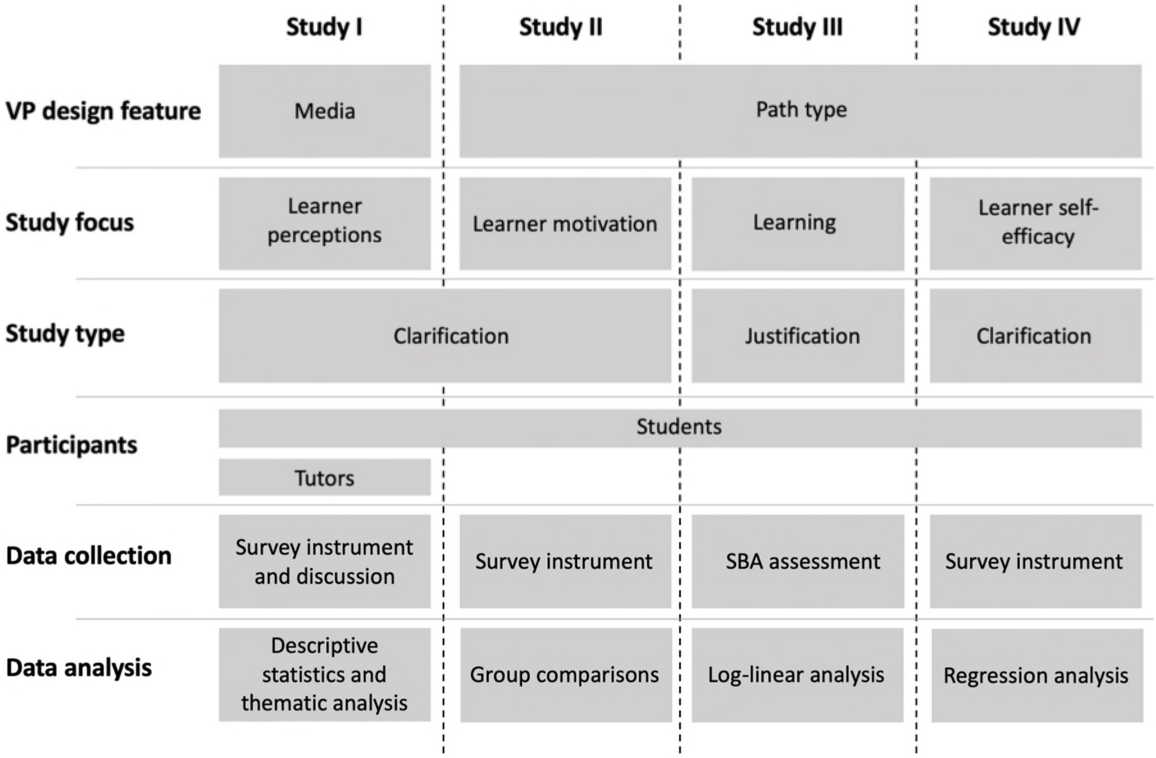
In all of studies II-IV we used an experimental design that compared interventions of different designs or types. Cook and Beckman (2010) have argued that controlled experiments comparing interventions with no intervention have little value in education research. Cook (2009) has further discussed the limits of evidence that can be provided by and conclusions that can be drawn from randomised controlled trials in education considering both the prevalence of confounding factors that cannot be effectively controlled, and the challenges of generalising results from a single unique setting to another (Cook, 2010a). To this end, evidence from a randomised controlled trial design must be seen as only one piece of contributing evidence towards establishing an accepted knowledge about the effectiveness of a resource, and be used to test theories rather than simply demonstrate a measurable effect (Cook, 2012b). Cook and Beckman (2010) have also supported the suggestion by Norman (2003) that randomisation in such experiments only controls for issues of selection and maturation, and that other variabilities cannot be accounted for simply by randomising participants; to this extent, a well-designed non-randomised study can make a greater contribution to the base of evidence than a poorly controlled randomised experiment.

In this project, we have attempted to address these concerns about experimental study designs by repeating them at multiple institutions in an attempt to demonstrate that the findings hold in multiple settings, thus making a greater contribution to the evidence base in support of our findings. In educational research, the risk of volunteer bias impacting upon our results is high (Callahan, Hojat, & Gonnella, 2007). To mitigate against this, we have implemented our interventions within the regular teaching curriculum at the institutions and allowed participants to opt-out of the completion of outcome measures rather than the receipt of the intervention. This has in turn impacted upon our approach to randomisation of participants; since teaching has been conducted in regular teaching groups, we have taken these teaching groups or clusters as the units of randomisation, assigning these to the different study arms. As in much educational research, blinding of participants to their allocation was not possible (Norman & Eva, 2013).

When delivering an intervention to students within their curriculum, and when blinding of their allocation is not possible, there is a significant risk of response bias. Students, wanting their tutors to give them a good grade and knowing if they are in the intervention group or otherwise, may naturally want to respond favourably and tell the tutors what they think they want to hear for fear of possible reprisals if they do otherwise. For this and ethical reasons, it was crucial that student responses be anonymous. For practical reasons, when running experiments across multiple centres in multiple languages, it was also not possible to pseudonymise responses; survey instruments had to be completed on paper due to limited availability of equipment and the need for responses to be completed within teaching sessions, therefore we could not reliably implement a system to encode identities and maintain anonymity. The end result is a significant limiting factor in the power of our experiments and conclusions; we cannot identify a response to an individual, and thus cannot link that individual’s responses across multiple outcome measures. This prevents us from using within-participants or repeated measures designs in our analysis of the collected data which would potentially strengthen the value of our conclusions. Similarly, since our unit of analysis is responses collected from individuals despite allocations being in clusters, we cannot statistically compensate for within-group clustering effects. This limiting factor must therefore be accounted for and considered in our discussion and conclusions. To that end, replicating our results in a repeated study design was crucial for our findings.

5 METHODS

A visual overview of the methods applied to the studies is shown in Figure 1.



	Study I	Study II	Study III	Study IV
VP design feature	Media	Path type		
Study focus	Learner perceptions	Learner motivation	Learning	Learner self-efficacy
Study type	Clarification		Justification	Clarification
Participants	Students Tutors			
Data collection	Survey instrument and discussion	Survey instrument	SBA assessment	Survey instrument
Data analysis	Descriptive statistics and thematic analysis	Group comparisons	Log-linear analysis	Regression analysis

Figure 1 Overview of studies

5.1 EMPIRICAL SETTINGS

5.1.1 St George’s, University of London

The base for all my work in this thesis has been St George’s, University of London (SGUL), where I work within the eLearning team in the Institute of Medical and Biomedical Education. SGUL is the United Kingdom’s only specialist medical and healthcare institution, and the only UK university based in a hospital. The Institute of Medical and Biomedical Education is responsible for the co-ordination of teaching and learning for the majority of SGUL’s taught undergraduate and postgraduate programmes. These programmes include the traditional medicine degree (MBBS5), as well as a companion medicine programme designed for graduate entry that admits graduates from any discipline, including the arts and humanities (MBBS4). The two medical programmes merge during a transition year prior to pre-clinical practice. Figure 2 shows the structure of the medical curriculum at SGUL, including the merging of the two medical programmes.

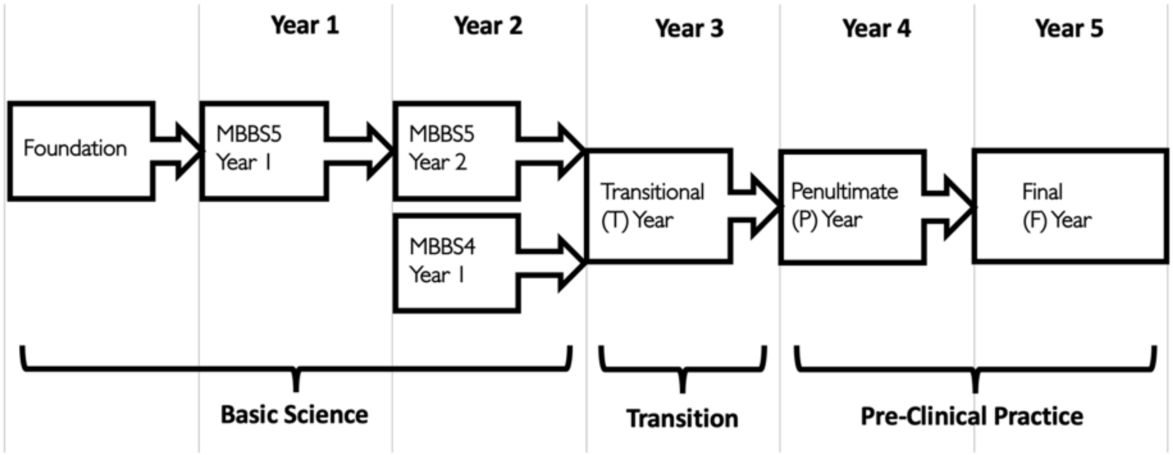


Figure 2 Structure of the undergraduate medical curriculum at St George's, University of London

5.1.2 The Training Against Medical Error project

Studies II-IV in this thesis took place as part of the TAME (Training Against Medical Error) project (“TAME project - Homepage,” n.d.). The 3-year project was funded by the European Commission Erasmus+ programme as part of its capacity building programme and began in October 2015. The project partnership includes partners from 10 academic institutions in the United Kingdom (St George’s, University of London), Greece (Aristotle University of Thessaloniki), Sweden (Karolinska Institutet), Czech Republic (Masaryk University), Kazakhstan (Karaganda State Medical University, the project co-ordinators, and Astana Medical University), Ukraine (Bukovinian State Medical University and Zaporozhye State Medical University) and Vietnam (Hanoi Medical University and Hue University of Medicine and Pharmacy).

In capacity building projects, the key objective is to develop improved educational “capacity” within the “partner countries” (i.e. those that are not EC members) and to share the expertise of the “programme” countries who are members of the EC. However, the relationships amongst the partnerships are often more complex than this and offer opportunities for educational development by all members of the consortium. Research outputs often form a key component of the sustainability of a project, and the ability to have a lasting impact beyond the project lifetime.

In the case of the TAME project, the aim of the project was to develop programmes of medical error teaching in the partner institutions by designing virtual patients for use in small group settings, and to implement these within the medical curricula of the institutions. The studies in this thesis formed part of the evaluation plan for the project and explored the impact of different virtual patient design features in this context.

The interventions in the studies were delivered within the paediatrics teaching module of the undergraduate medical curriculum at each partner institution.

5.1.2.1 Astana Medical University, Kazakhstan

Astana Medical University (AMU) was founded in 1997 and achieved university status in 2009. It has seven faculties: Internal Medicine, Dentistry, Public Health, Nursing, Preventive Care, Pharmacy and Postgraduate education. The university has more than 5,000 students enrolled in its programmes.

Training to be a practicing physician in Kazakhstan requires five years studying for a bachelor’s degree in General Medicine, followed by a two-year internship. After this students can begin to practice in general medicine or surgery, or can undertake a further residency of two to three years in order to train in a particular specialty. At AMU, paediatrics teaching takes place in year 4 and 5 of the undergraduate medicine course. The intervention in these studies was introduced in the module “Children’s diseases” in year 4 of the curriculum.

5.1.2.2 Karaganda State Medical University, Kazakhstan

Karaganda State Medical University was established in 1950, and has four faculties: General Medicine and Dentistry, Internship, Continuous Professional Development, and Preventive Medicine, Biology and Pharmacy. KSMU were the project coordinators for the TAME project, and had previously implemented problem-based learning in their curriculum as part of a project called ePBLNet (Riklefs et al., 2018).

As with AMU, the medical training at KSMU follows the nationally regulated structure of a five-year bachelor’s degree, followed by a two-year internship. The paediatrics teaching in the undergraduate medical curriculum takes place in year 4 of the course, and the intervention in these studies was delivered in as part of that teaching.

5.1.2.3 Bukovinian State Medical University, Ukraine

Bukovinian State Medical University (BSMU) has existed in a variety of forms since 1931 and took its current name in 2005. It currently has more than 4000 students enrolled in its programmes.

The medical curriculum in Ukraine requires six years of study and is divided into preclinical and clinical training. BSMU had not used problem-based learning approaches prior to the TAME project. Training in paediatrics is integrated across a range of modules and takes place in the fifth and sixth years of the undergraduate medical curriculum.

5.1.2.4 Zaporozhye State Medical University, Ukraine

Zaporozhye State Medical University (ZSMU) was founded in 1994, although it has existed in different forms since 1903. The university has eight faculties and over 10,000 students.

As at BSMU, the medical curriculum at ZSMU requires six years of study and conforms to the Bologna process for establishing common European standards and systems. The paediatrics training and the delivery of the interventions in these studies took place in the fifth year of the undergraduate medical curricula.

5.1.2.5 Hanoi Medical University, Vietnam

Hanoi Medical University (HMU) was founded in 1902 and is one of the oldest universities in Vietnam. HMU had not implemented problem-based learning approaches prior to the TAME project.

The medical curriculum at HMU requires six years of training. The paediatrics virtual patients in the TAME project were delivered to students as part of a module called Pediatrics and Infectious Diseases, which students complete in the fourth year of their studies.

5.1.2.6 Hue University of Medicine and Pharmacy, Vietnam

Hue University of Medicine and Pharmacy (HUMP) was established in 1957 and took its current name in 2007. The institution has seven faculties related to medicine and healthcare.

The undergraduate curriculum is designed in accordance with guidelines from the national Ministry of Health and requires six years of study. The first two years of the course focus on basic science training, and the next two years focus on basic medical sciences such as anatomy, microbiology and physiology. The final two years expose students to clinical settings. Paediatrics training takes place in the sixth year of the course, and it is in this module that students received the interventions from the TAME project.

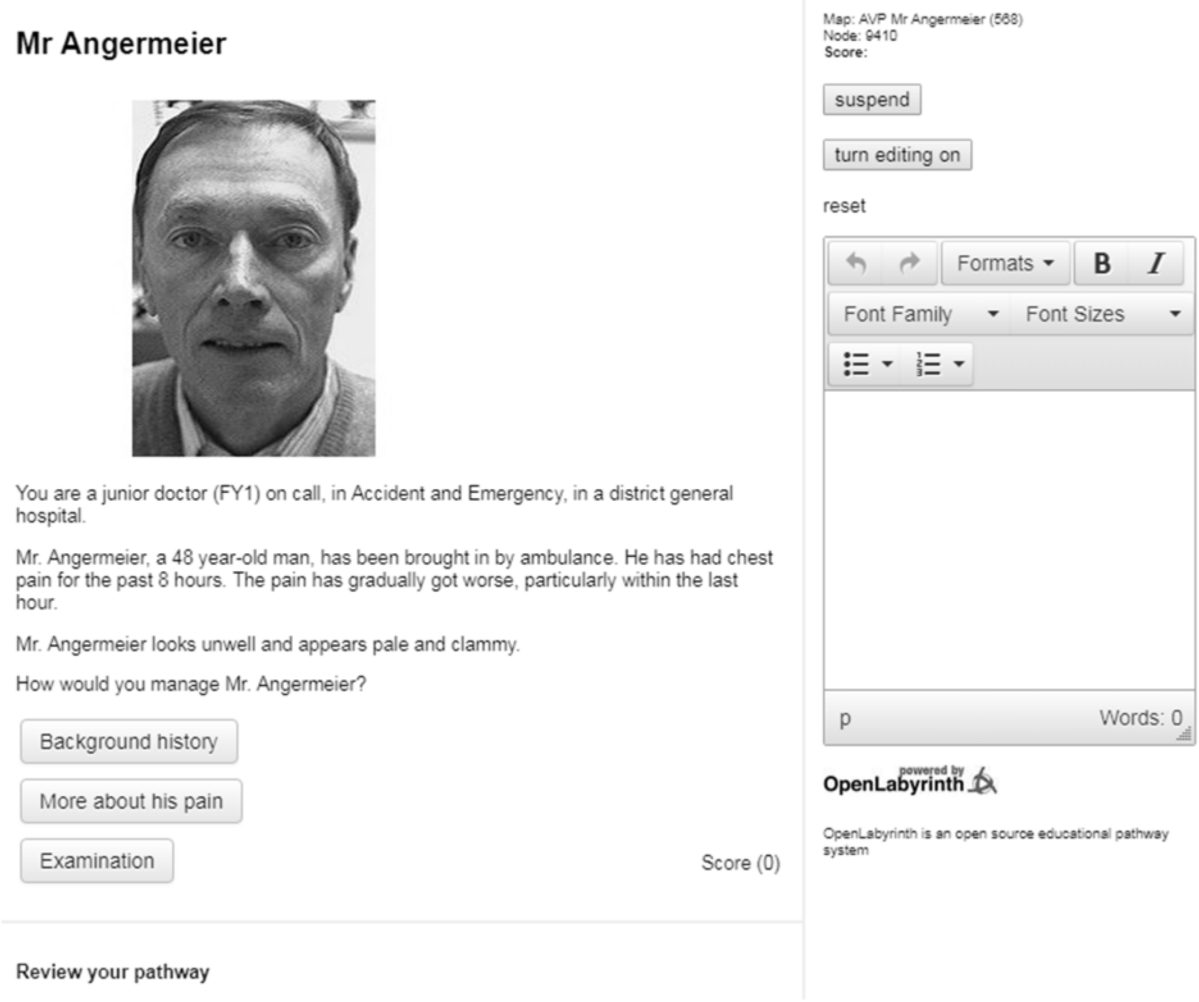
5.1.3 Small group teaching

The interventions in all of the studies were delivered to students in small group teaching sessions which built upon some of the principles of problem-based learning while also incorporating virtual patients. This approach was established at St George’s, University of London (Ellaway et al., 2015). The sessions took place in purpose-designed rooms, laid out around a large central table. A computer was situated on a separate table at the end of each room and connected to a projector which displays the screen to the whole group. Whiteboards for group note-taking are provided on the other walls. The teaching sessions lasted for 3 hours and were facilitated by tutors that had been trained to facilitate problem-based learning.

5.1.4 OpenLabyrinth

The virtual patients used in these studies were delivered using the virtual patient authoring and publishing system OpenLabyrinth (version 2 was used in study I, and version 3 was used in studies II-IV). OpenLabyrinth is an open source web-based system developed by the OpenLabyrinth Development Consortium, led from the University of Calgary (Open Labyrinth Development Consortium, n.d.), and which builds upon an earlier system developed at the University of Edinburgh (Begg, Ellaway, Dewhurst, & Macleod, 2007). The system is freely available but requires an available server and some technical expertise to install and run. No installation is required on end-user machines for either authoring or playing virtual patient cases.

OpenLabyrinth is particularly designed to deliver virtual patient cases that follow a branching model (Huwendiek, De Leng, et al., 2009). By placing learners in the role of a clinician within a patient scenario, branching virtual patients are able to engage learners in making decisions about how to proceed in a case narrative and provide personalised feedback to the learner about the consequences of those decisions through changes in the narrative outcomes (Poulton et al., 2009). An example of a screenshot from an OpenLabyrinth virtual patient is shown in figure 3.



Mr Angermeier

You are a junior doctor (FY1) on call, in Accident and Emergency, in a district general hospital.

Mr. Angermeier, a 48 year-old man, has been brought in by ambulance. He has had chest pain for the past 8 hours. The pain has gradually got worse, particularly within the last hour.

Mr. Angermeier looks unwell and appears pale and clammy.

How would you manage Mr. Angermeier?

Map: AVP Mr Angermeier (568)
Node: 9410
Score:

OpenLabyrinth is an open source educational pathway system

Background history
More about his pain
Examination
Score (0)
Review your pathway
suspend
turn editing on
reset
Formats
B
I
Font Family
Font Sizes
p
Words: 0
powered by
OpenLabyrinth

Figure 3 Screenshot from a virtual patient delivered using OpenLabyrinth

On this screen, there are 3 available option choices available to learners ("Background history", "More about his pain", "Examination").

5.2 PARTICIPANTS

5.2.1 Study I

The primary participants in study I were medical students at St George's, University of London enrolled in the transition year of their course. The transition year includes an extensive problem-based learning curriculum, taught in mixed groups of both undergraduate entry students (in their third year) and graduate entry students (in their second year).

The students received the study intervention as part of their regular curriculum, so all students who attended the teaching session received the intervention. However, those students that wished to opt-out of participating in the study were able to do so by not completing the feedback activity.

Additional participants in the study were the problem-based learning tutors who completed the feedback activity or took part in a discussion and review session. These tutors were employed by St George's, University of London and worked with their assigned student groups throughout the year. All tutors were trained to facilitate problem-based learning sessions and were not required to have subject-specific knowledge.

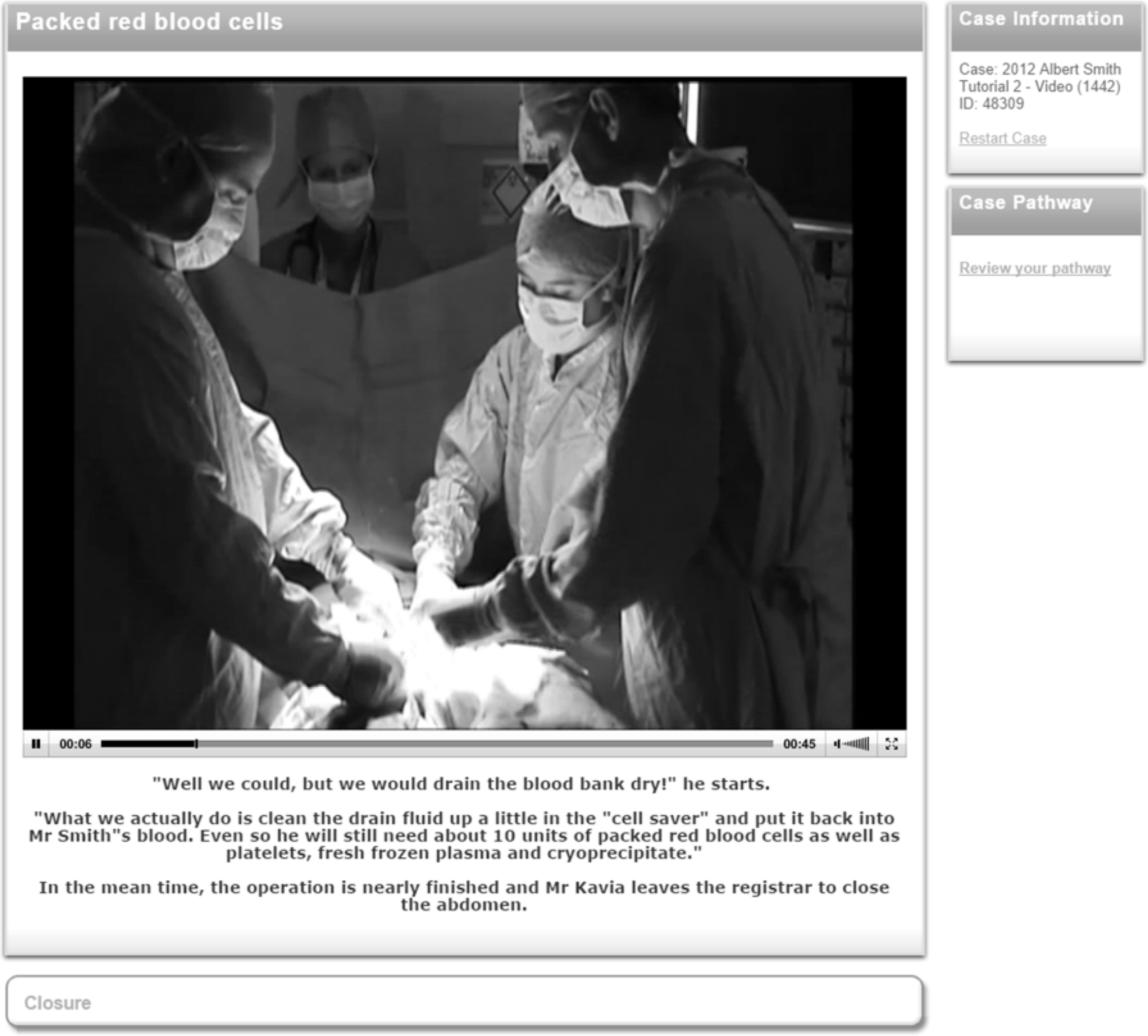
5.2.2 Study II-IV

The participants in studies II-IV were undergraduate medical students enrolled in the Paediatric teaching blocks at six partner country institutions within the TAME project: Karaganda State Medical University and Astana Medical University (Kazakhstan), Bukovinian State Medical University and Zaporozhye State Medical University (Ukraine), Hanoi Medical University and Hue University of Medicine and Pharmacy (Vietnam). The interventions were delivered to students as part of their regular curriculum, but students were able to opt-out of completing the data collection instruments.

5.3 INTERVENTIONS

5.3.1 Study I

Having identified a suitable virtual patient case in the St George's, University of London problem-based learning curriculum, the second tutorial of the case was adapted to replace text-based elements with videos recorded in the St George's Advanced Patient Simulation centre. These videos recreated the content of the text elements using actors and varied in length between 45 seconds and 4 minutes. The adapted intervention was delivered to participating students as part of their regular problem-based learning curriculum. A screenshot of the virtual patient containing a video element is shown in figure 4.



"Well we could, but we would drain the blood bank dry!" he starts.

"What we actually do is clean the drain fluid up a little in the "cell saver" and put it back into Mr Smith"s blood. Even so he will still need about 10 units of packed red blood cells as well as platelets, fresh frozen plasma and cryoprecipitate."

In the mean time, the operation is nearly finished and Mr Kavia leaves the registrar to close the abdomen.

Figure 4 Screenshot showing a video clip embedded in the virtual patient activity

Image used under a CC BY 2.0 license from the original JMIR publication at https://www.jmir.org/2015/6/e151. (Woodham et al., 2015)

5.3.2 Studies II-IV

For these studies a series of six virtual patients were created which aimed at developing student awareness of medical errors. These virtual patients were specifically set in the Paediatrics area of medicine, and built upon an approach to medical error training amongst undergraduate learners involving the use of game-informed interventions in an activity which requires students to identify and classify errors based upon a framework for describing errors in practice (Vaughan et al., 2012). Within the virtual patient case narratives there were a number of possible errors that could arise, with the possible outcomes that these errors would result in harms to the patient. Each virtual patient would conclude with content to debrief and facilitate reflection by students upon the errors that were made. The aims of the virtual patients were not to model poor decision making, but to allow learners to develop their awareness of the types of errors that can take place and to anticipate at what stages of patient care errors might be most likely to occur.

The virtual patients were initially designed in English and were then translated and culturally adapted for use in Kazakhstan, Ukraine and Vietnam. Each case was designed in two variants; a linear version and a branching version. Participants were allocated into groups to receive either the branched or the linear version of the cases. Learners only had access to the virtual patient cases during the small group sessions and were not given repeat access before all outcome measures had been taken.

In the branched version of the cases, all the decision points, options and pathways were made available to the learners, while in the linear cases only one pathway was available. The linear cases did not represent the "ideal" pathways in which no errors are made; the linear pathways included errors, and learners using those cases did not have the opportunity to avoid those errors. An example of a case map which includes both the linear and branching pathways is shown in Figure 5.

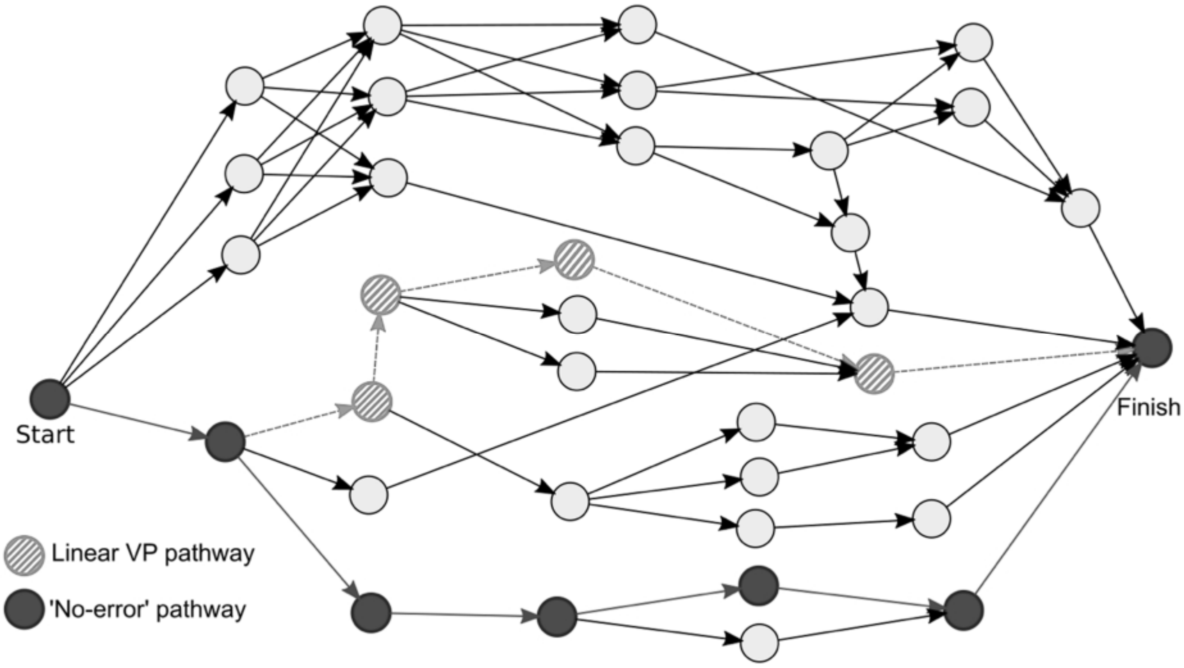


Figure 5 Map showing an example of the structure of a virtual patient designed to teach about medical error

The pathway that represents good patient management decisions and includes no errors is shown in solid nodes. The linear variant of the virtual patient is shown by the pathway that includes the diagonally shaded nodes. Image published by PLOS ONE and made available under a CC BY 4.0 licence. (Woodham et al., 2019)

5.4 DATA COLLECTION

5.4.1 Study I

We collected data for this study from three sources: a student survey, a survey of the problem-based learning tutors that facilitated the sessions, and a discussion and review session with the same tutors.

We adapted the student survey instrument from a published instrument for evaluating the student experience of using virtual patients (Huwendiek et al., 2015), adding additional questions for the specific purpose of evaluating the use of video resources in the case. Participating students completed the survey on paper at the end of the problem-based learning session.

The tutor survey instrument was adapted from an instrument used in a previous study addressing perspectives on a virtual patient activity delivered in a virtual world (Conradi et al., 2009). This survey instrument was similarly completed on paper at the end of the problem-based learning session.

A semi-structured approach was used for the discussion and review session, with a question script developed in advance. The review session was led by a male researcher, known to some of the tutors, who was studying for a doctorate and employed at St George’s. The session was run at St George’s, and no repeat sessions were conducted. The session was audio recorded and manually transcribed for analysis.

5.4.2 Studies II-IV

In these studies, we collected data from the student participants using a series of instruments covering different domains. A diagram of the different data collection activities is shown in figure 5.

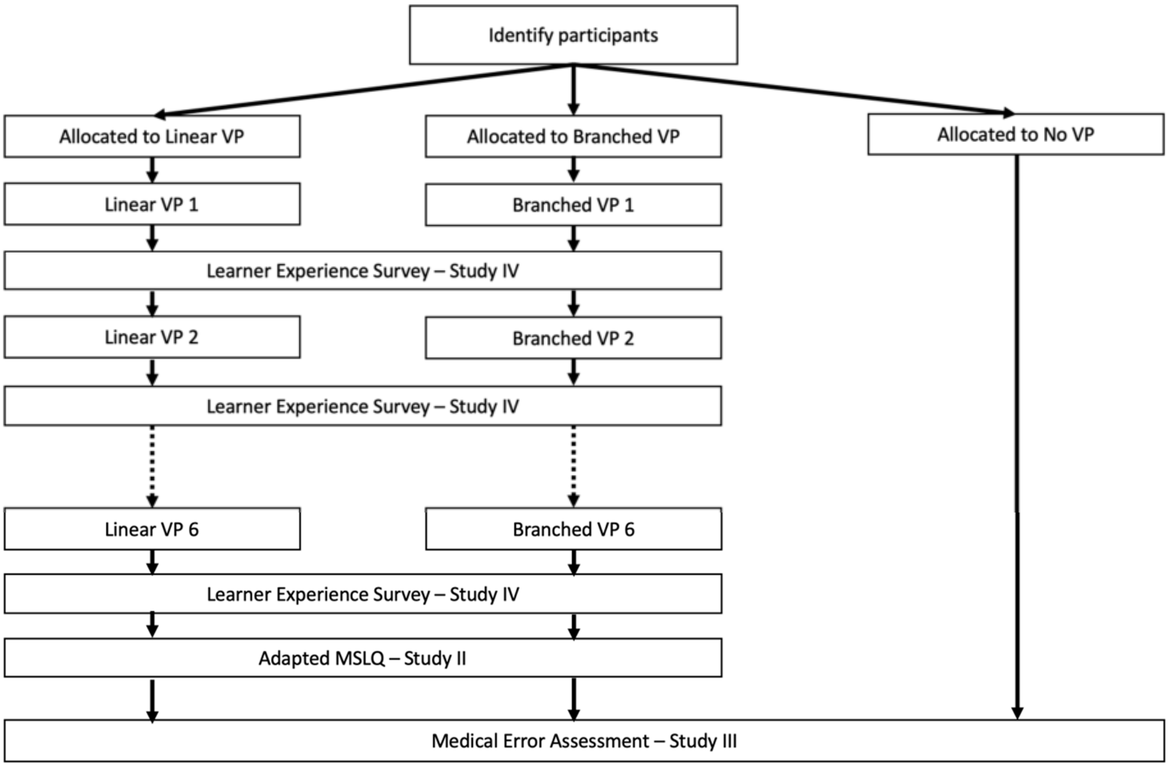

Identify participants
Allocated to Linear VP
Allocated to Branched VP
Allocated to No VP
Linear VP 1
Branched VP 1
Learner Experience Survey – Study IV
Linear VP 2
Branched VP 2
Learner Experience Survey – Study IV
Linear VP 6
Branched VP 6
Learner Experience Survey – Study IV
Adapted MSLQ – Study II
Medical Error Assessment – Study III

Figure 6 Diagram showing data collection activities for studies II-IV

All instruments were translated into Russian, Ukrainian and Vietnamese so that they could be clearly understood by the participants, with translations checked by a second native language speaker for accuracy and clarity.

5.4.2.1 Study II

In this study we asked participants to complete a modified version of the Motivated Strategies for Learning Questionnaire (MSLQ) (Pintrich, Smith, Garcia, & McKeachie, 1991; Pintrich, Smith, Garcia, & Mckeachie, 1993). This instrument was given to the students once they had completed all six virtual patient activities.

The MSLQ in its original form uses 15 different subscales to measure different aspects of learner motivation and learning strategies. Of these 15 subscales, we used 6 that were applicable to this study: Intrinsic Goal Orientation, Task Value, Control of Learning Beliefs, Self-Efficacy for Learning and Performance, Critical Thinking and Help Seeking. We also adapted the language used in the survey for the context, primarily replacing references to “class” with “cases”.

5.4.2.2 Study III

We developed an assessment instrument that was designed to assess the student participants learning and awareness of the concepts of medical error. This instrument contained 54 single-best answer questions in 3 sets of 18 questions which related to the content of the virtual patient cases with varying degrees of closeness. One set of questions assessed learning which directly related to the decision-making options within the virtual patients. Another set of questions matched the same area of medicine, diagnoses and management approaches as the virtual patients, but not the same decision-making options. The final set of questions covered the same broad subject areas of medicine as the virtual patient but addressed entirely different diagnoses and management approaches. The purpose of these different sets of questions was to develop an understanding of how well the learning about medical errors from the virtual patients transfers to different areas of medicine.

Student participants in both the linear and branched groups completed the assessment under controlled conditions following completion of all the virtual patient cases. A third control group that received only traditional didactic teaching methods for medical error also completed the assessment. Participant scores were calculated by providing one mark per correct answer. There was no negative marking applied for incorrect answers.

5.4.2.3 Study IV

In this study we constructed a survey instrument to capture a range of outcome measures relating to the student experience of a specific case. This instrument combined a number of previously published instruments, building upon the approach adopted by Creutzfeldt, Hedman, Medin, Heinrichs, & Felländer-Tsai (2010).

The survey incorporated items from existing instruments designed to evaluate virtual patient design (Huwendiek et al., 2015), self-efficacy (Bandura, 2006), and mental strain (Borg & Borg, 2001). The survey also captured information about affected states resulting from the intervention using the International Positive and Negative Affect Schedule Short Form (I-PANAS-SF) (Thompson, 2007; Watson & Clark, 1988). The instrument was completed by student participants after each virtual patient, meaning that an individual participant would complete the survey instrument up to 6 times in total. Individual responses were not identifiable, so responses for an individual could not be compared across virtual patient cases.

5.5 DATA ANALYSIS

5.5.1 Study I

We generated descriptive statistics from the structured responses, converting Likert scale values to ordinal form. Since the data was ordinal and therefore not normally distributed, we used 2-tailed Mann-Whitney U tests to test whether the distributions for graduate entry and undergraduate entry were significantly different.

The unstructured open responses from the survey and tutor review session were analysed by a single researcher using a theoretical thematic analysis approach. This approach was selected as it allowed us to specifically investigate the surface aspects of the data related to the research question (Braun & Clarke, 2006).

The analysis was undertaken in the software package ATLAS.ti (“ATLAS.ti: The Qualitative Data Analysis & Research Software,” n.d.) and the data was manually coded, taking individual sentences as the unit of analysis. The first reading of the data was performed using an open-coding approach, identifying themes grounded in the data. A second reading iterated upon this in the same way, refining the themes and identifying insights missed during the initial reading. Subsequent readings took an axial coding approach, refining connections between codes and merging them to produce distinct thematic groupings.

5.5.2 Study II

All data analysis was conducted using the R statistical environment (R Core Team, 2019).

We conducted a reliability analysis of the survey to assess the internal consistency of the sub-scales in the context of our study, calculating Cronbach’s alphas, corrected item-total correlation and correlation matrices. The analysis considered each translation of the survey separately, to ensure that the meaning and internal consistency was retained in each language, particularly in relation to the adaptations made to the MSLQ. A guiding threshold for alphas of 0.7 was applied for the retention of items in a sub-scale, but this was not applied rigidly if the scale was felt to have value in interpreting our results.

We reviewed demographic information broken down by institution, study arm and gender, and calculated descriptive statistics for the age of respondents. We calculated sub-scale values for each individual by taking the mean of their responses for the items of that sub-scale (Pintrich et al., 1991). We then calculated descriptive statistics (mean and standard deviation for the sub-scales at each institution, separating the linear and branched groups. These results were plotted along with 95% confidence intervals. We also calculated a total mean for each sub-scale combining responses from all institutions. We used two-tailed unpaired student t-tests to test the significance of differences between the linear and branched groups.

5.5.3 Study III

We conducted the data analysis for each of the three groups of questions separately, with each individual receiving one score for each group of questions. We used the R statistical environment for all analysis (R Core Team, 2019), calculating descriptive statistics and plotting means and frequency densities.

We ran Levene’s test across the institutions and study arms, which indicated that the variances were not equal across the groups, violating the assumptions for ANOVA. We therefore transformed each score into a categorical variable for each question block: Low (scores less than or equal to 6), Medium (scores between or equal to 7 and 12), and High (scores of 13 or over). Contingency tables of these categorical scores were calculated and a log-linear analysis was then conducted to fit a statistical model to the data.

5.5.4 Study IV

We analysed data from each virtual patient case separately so that the responses in each dataset were independent. Although individuals completed a response for each of the six virtual patient interventions we were unable to link responses to individuals, so we could not use a repeated-measures analytic approach. We included partial responses in our analysis but required responses to be complete within the measures for any given sub-scale for a response to be included in the analysis for that sub-scale.

We calculated descriptive statistics using Microsoft Excel, and generated plots using the R statistical environment (R Core Team, 2019). All other analysis was conducted using R. Cronbach’s alphas were calculated for internal consistency and Shapiro Wilk tests used to test assumptions of normality. Student t tests and Mann-Whitney U tests were conducted to test for significant differences between the linear and branched responses for the measured variables: self-efficacy, authenticity of patient encounter, cognitive strategies, global score, mental strain and I-PANAS-SF score.

A hierarchical regression analysis was performed in five stages to fit models to the data and investigate the predictive power and dependencies of the measured outcomes with post-intervention self -efficacy. The exposure to the linear or branched intervention was the fourth step in this analysis, and ANOVA tests were used to examine the significance of the inclusion of this variable in the model.

6 ETHICAL CONSIDERATIONS

The studies in this project involved student participants, so it was crucial to receive ethical approval for the work and to conduct the research in accordance with the Declaration of Helsinki (2013).

Study I was reviewed and approved by the chair of the St George's, University of London Ethics Review board and approved by the undergraduate program course director.

Studies II-IV were reviewed and approved by the Committee on Bioethics at the TAME project coordinators, Karaganda State Medical University (assigned no. 271). All project partners confirmed consent to participate in the study under the signed partnership agreement 2015-2944/001-002. Local approval for the project was granted at all countries and institutions following review from local bioethical committees, ministries and/or Heads of Curriculum Development and student experience/welfare.

6.1 ETHICAL CONSIDERATIONS RELATING TO STUDENT PARTICIPANTS

A key consideration was to ensure that student participants in the studies did not suffer any educational disadvantage, nor hinder their course progression, as a consequence of participating in the studies. This represents an application of the *non-malfeasance* or *no harm* principle of research ethics and has several implications for the studies in this project.

In experimental research, we might naturally set up a trial of "intervention vs no intervention", where one student group receives an educational intervention and the other group does not, acting as a control group. This may potentially be considered ethical if the researchers have no justifiable reason to believe that provision of the intervention will either benefit or disadvantage those receiving it. However, given that the intervention has been designed for a purpose, it is far more likely that a benefit has been hypothesised. Indeed, Cook and Beckman (2010) argue that such no-intervention controls are almost certain to demonstrate a significant effect, since time spent learning via any method will likely have an impact. For this reason, in the studies in this project all comparisons were made between interventions including different design features, or with a comparison to lecture-based teaching. After all outcome measures were taken, all study participants were also given access to both interventions to further ensure that no learners were disadvantaged.

Similarly, issues of data protection for student participants needed to be considered, particularly given the nature of these studies in which students were self-reporting through the completion of survey instruments. In all studies student responses to surveys were *anonymous,* which served to ensure that the *confidentiality* of student responses was maintained. In these predominantly self-report studies this was crucial to ensure that participants were able to answer questions honestly, and to reduce the risk of response bias. By making responses anonymous we intended that participants would not feel pressure to self-censor their responses and feel able to provide negative feedback about the resources without risking upsetting tutors. Similarly, it was intended that participants could answer questions about their motivation and learning strategies without shaping their response in anticipation of what they believe tutors might want to hear. In study III, the assessment responses were not anonymous to their institutional tutors, but responses were anonymised from the researchers and before analysis took place; since the marking criteria was objective this did not carry the same risk of response bias or bias on the part of assessors.

Although responses were anonymous, there was a risk that the confidentiality of the responses could be threatened if combinations of data collected about identifiable characteristics allowed the identity of individuals to be deduced. Examples of the demographic data that was collected in the studies were institution, age and gender. This was mitigated against by the multicentre nature of the work (such that individuals were not known to the researcher conducting the data analysis) and the number of participants being sufficiently large that combinations of the data were not unique and thus not identifiable.

In all of the studies in this project, interventions for the study were delivered as part of the curriculum-level teaching that students received. This poses a challenge for the principle of *informed consent*, since the interventions were effectively mandatory for all students enrolled in the course. We addressed this by allowing students to opt out of participating by not completing the survey instruments and making these voluntary. At the start of all survey instruments the purpose of the research was made clear, along with information about the participants rights to both be anonymous and to withdraw consent and participation at any time. Consent statements were included in all surveys, with participants asked to explicitly confirm their consent to participate. Similarly, tutors that participated in the discussion and review session in study I were provided with information about the purpose of the work, that responses would be anonymous, and were clearly informed that participation was voluntary and could be withdrawn at any time.

The multi-centre nature of studies II-IV represented a challenge in handling the differing cultures and languages of collaborators. The studies involved participants from six institutions in Ukraine, Kazakhstan and Vietnam. Ethical approval for the study was obtained at all participating institutions. Translations and cultural adaptations were made to the virtual patient resources which were confirmed as accurate by native speakers. This ensured that the meaning of consent statements and information regarding confidentiality and withdrawal of participation was clear, necessary to maintain the principles of *informed consent* and *confidentiality*.

6.2 ETHICAL CONSIDERATIONS RELATING TO PATIENTS AND RESOURCES

The studies in this doctoral project do not directly relate to patients in any way, and there are no patient participants in any of the studies. However, an area of ethical relevance to patients relates to the virtual patient cases themselves, and the principles of *informed consent* and *confidentiality*. In many instances the authors creating virtual patients may do so based upon real-life patient experiences that they have encountered in their clinical practice. Although the case may be inspired by a particular patient or patients, no patient-specific information that may identify the patient can be used. This may include supplementary media items such as videos, scans and images, which should be anonymised and patient consent obtained. No identifiable patient information was used in the virtual patients used in the studies in this project.

If third party content from image libraries or other media is used in virtual patients, the provenance of the material must be accounted for in order to ensure that informed consent from the patient was provided for this use. In addition, when using content from external sources, it must be ensured that content is appropriately licenced and that the terms of that licence are complied with. Where attribution is required in the licence terms, this must be provided. All images or materials used in the virtual patient resources in this project were appropriately licenced and attributed.

Original video content was created for the virtual patient resource in study I. This video, like the virtual patient resource, was the intellectual property of St George’s, University of London and was permitted for use. All actors in the video signed a consent form to grant permission for their image and likeness to be used in the virtual patient resource and associated research.

7 SUMMARY OF FINDINGS

7.1 STUDY I

We received a total of 119 responses to the student survey, giving a response rate of 75.3% and providing a total of 274 open-text comments. The tutor survey received 8 responses, giving a response rate of 44% with 21 open-text comments. Additional open-ended responses were also received from analysis of the tutor review and discussion session transcript.

We calculated descriptive statistics from the student responses and non-parametric 2-tailed Mann-Whitney U tests were run on all likert items to determine whether the distributions for the graduate entry and undergraduate entry were different. These indicated that there were no significant differences at the 5% level ($p < .05$). We therefore concluded that there was no evidence to support separating the two entry points in our analysis.

A total of 61% (n=69) responses indicated that they felt that the use of video in the tutorial was effective. Despite this, 65% (n=65) of responses expressed a preference for text-based scenarios over those using video in this context.

An open-coding process of both student and tutor comments led to 67 distinct codes being identified in the data. 5 of these codes were automatically generated by the software as part of the process of importing the transcripts; these were unrelated to the research question and were thus excluded from the analysis. The remaining codes were reviewed for common meaning and thematically linked, yielding eight distinct themes:

1. *Level of engagement*

Although the level of engagement was a priority for many commenters, opinion was divided amongst participants with regards to whether the use of video had a positive or negative impact upon levels of engagement.

2. *Harder to identify relevant information from video*

Participants identified that students missed more key information in the video, and that this had a negative impact upon discussion.

3. *Text can be reviewed more easily than video*

Students identified that the use of video limited their ability to refer back to the information source and to check their facts during group discussion.

4. *Video slows the pacing of problem-based learning*

Many participants commented that the use of video slowed the pace of the session significantly, with some estimating that it increased the length of the session by around 30 minutes. This can in part be attributed to the videos requiring repeat viewings in order to extract the necessary information, with 45 of the students indicating that they watched the videos more than twice on average.

5. *Video made the scenario seem more real*

Students indicated that video offered a greater ability to suggest the need for urgency and helped them to feel present, making the scenario feel more realistic. They described video as being able to provide a greater range of visual clues which could impact upon the decision-making process.

6. *Video is well-suited to displaying procedures*

One of the videos showed a simulated surgical procedure. This video was not designed to model the surgical process, but several participants commented that video was a valuable medium for displaying exemplars of procedures that could be used as aids to learning.

7. *Students favour a combination of text and video*

Several students suggested that the ideal combination would be to provide both video and text, with a common suggestion to provide a video for a first viewing and then a text transcript for subsequent review.

8. *The quality of the video resource*

It was clear that ensuring that the video resource was high quality was crucial if it was going to be accepted. Participants raised concerns about the quality of the acting, the regularity of the cuts, and the clarity of the sound in the video clips provided.

Our findings established that the use of video had positive benefits for some learners but had the potential to also negatively impact the pacing and dynamic of small-group problem-based learning activities. We concluded therefore that an optimal approach in a problem-based learning setting would be to use video only for those elements to which it is particularly well-suited, such as displaying procedures. Such an approach would maximise the benefits of the use of video, while minimising the negative impacts. We noted that these findings were context-specific and should not be held to apply in other settings such as lectures or self-directed learning without further research.

7.2 STUDY II

We received 346 out of a possible 384 responses to the survey, providing an overall response rate of 90.1%, with variation between institutions of between 80% and 100%. Demographic information indicated that the average age of participants was between 21 and 24 years old depending on institution. There were a higher number of female participants at all institutions, and this was reflected in the groups that received both the linear and branched interventions. A reliability analysis indicated a generally good level of internal consistency for the subscales in the survey instrument, although two items were dropped to ensure that all but one subscale had alphas above the 0.7 threshold. The *Help Seeking* subscale had a calculated alpha of 0.68 but we deemed this shortfall to be sufficiently small to retain the scale as having value in interpreting the results.

Two-tailed unpaired t-tests run for each institution separately indicated that there were no significant differences at the 5% level between the linear and the branched groups in the majority of the subscales. Those instances where a significant difference was identified did not show consistently across all institutions; indeed, when responses from all institutions were combined and analysed as a single dataset no subscales indicated a significant difference between the linear and branched groups (Intrinsic Goal Orientation: Linear $\bar{x}$ = 5.718, Branched $\bar{x}$ = 5.865, p = .206; Task Value: Linear $\bar{x}$ = 5.771, Branched $\bar{x}$ = 5.931, p = .146; Control of Learning Beliefs: Linear $\bar{x}$ = 5.534, Branched $\bar{x}$ = 5.537, p = .979; Self-Efficacy for Learning and Performance: Linear $\bar{x}$ = 5.520, Branched $\bar{x}$ = 5.567, p = .675; Critical Thinking: Linear $\bar{x}$ = 5.393, Branched $\bar{x}$ = 5.591, p = .078; Help Seeking: Linear $\bar{x}$ = 5.234, Branched $\bar{x}$ = 5.229, p = .973).

Comparison of the mean ratings (for both linear and branching groups) across the different subscales and institutions did provide some evidence of a pattern that the institutions AMU, KSMU and ZSMU had a tendency to score marginally higher. A common factor is that these institutions had previously implemented a problem-based learning curriculum, so had more experience of delivering teaching in this style. In contrast, the other institutions were new to this teaching approach, and had been more recently trained to deliver this for the first time.

Overall, our findings indicated that neither learner motivation nor learning strategies were significantly impacted by the presence of decision-making elements in the virtual patient design (i.e. the use of a linear structure without decision-making elements, or a branched structure with decision-making elements). This finding was replicated across the institutions in the study.

7.3 STUDY III

We received a total of 457 responses from five institutions: 163 from the branched group, 158 from the linear group, and 136 from the group that received traditional teaching. One institution was subject to project delays, so their data was not analysed or included in the study.

Descriptive statistics were calculated, and illustrative plots created of the data. These plots indicated a similar pattern of results across all institutions when comparing the study arms and groups of questions. Looking at all the institutions combined, the branched intervention group scored highest ($\bar{x}$ = 9.15) on the group of questions linked to the decision points in the virtual patients, followed by the linear group ($\bar{x}$ = 7.61), then followed by the group that received traditional teaching ($\bar{x}$ = 6.51). In the second set of questions that mirror the area of medicine, diagnoses and management options but not the decision points as the virtual patient, the branched and linear groups performed similarly (branched: $\bar{x} = 7.81$, linear: $\bar{x} = 7.76$) ahead of the traditional teaching group ($\bar{x} = 6.20$). Finally, in the third group of questions which covered the same area of medicine but different diagnoses, all groups performed similarly (branched: $\bar{x} = 6.55$, linear: $\bar{x} = 6.29$, control: $\bar{x} = 6.29$). By inspection of visual plots, this pattern broadly held for all institutions with the exception of HUMP, in which all groups scored more highly in the third group of questions.

The three-way log-linear analysis based upon the 3-level categorisation of score (low, medium and high) produced a final model that included all effects for each of the three sets of questions. The likelihood ratio of this model was X^2 (0) = 0, p = 1, since the model retained all effects and was therefore a perfect fit for the data. The model indicated that the highest order interaction (Score Category x Intervention x Institution) was significant at the level $p < 0.05$ for all question groups (question group 1: X^2 (16) = 30.06, p = 0.018; question group 2: X^2 (16) = 28.47, p = 0.028; question group 3: X^2 (16) = 32.91, p =0.008). Removing the highest order interaction would therefore make the fit of the model significantly poorer, thus we retained all the interactions. There was a statistically significant relationship between each of the variables and both the intervention and the institution have a significant impact upon the score obtained.

Our findings indicate that the branched virtual patients improved learning around the specific items highlighted in decision points within the cases when compared with linear virtual patients. Although institution was shown to have a significant impact upon performance, our results demonstrated this same effect at all institutions, providing evidence of the generalisability of this finding.

Both the linear and branched virtual patients improved learning within similar diagnoses and management approaches when compared with traditional teaching, but here there was no apparent advantage to one virtual patient design over the other. There was no evidence that the learning from either virtual patient design transferred to other settings when further removed from the virtual patient content even within the same area of medicine.

We concluded that virtual patients which contain decision-making options in a branching design are beneficial tools for learning, but that in the context of this study there was little evidence of this learning being transferrable to other settings. This has implications for educational practice in suggesting that we should be designing virtual patients that directly allow learners to rehearse key patient safety decisions.

7.4 STUDY IV

A total of 2032 responses for the survey were received from all institutions (1065 from the branched group, and 967 from the linear group). For some virtual patients at particular institutions more responses were received than expected without a clear explanation, and the impact of this had to be considered when drawing conclusions from the study.

We calculated descriptive statistics, which indicated that for all virtual patient cases students rated their self-efficacy with higher scores post-intervention. Shapiro-Wilk tests confirmed that self-efficacy ratings were normally distributed, and student t-tests indicated that there were no significant differences between the reported self-efficacy of the linear and branched groups, with the exception of case 4 in which the linear group reported higher self-efficacy ratings ($p < .01$). Visual plotting of the reported self-efficacy post-intervention indicated a slight upward trend with exposure to more cases in both the linear and branched groups, and one-tailed student t-tests confirmed that the mean reported self-efficacy was significantly greater following case 6 than it was following case 1 for both groups (linear: $p < .001$, branched: $p < .001$).

Examination of the measures of authenticity of the patient encounter, cognitive strategies for the consultation, global score, mental strain and affected state indicated that there were no clear patterns indicating a significant difference between the linear and branched groups. We tested this using Mann-Whitney U tests, since Shapiro-Wilk tests of the data indicated that, with a few exceptions, the data sets to be tested were not normally distributed. The resulting p-values are shown in table 1. Although tests returned some significant results for specific cases, no conclusive patterns were consistently revealed across all cases.

Table 1 Study IV - p-values from hypothesis testing

	p-value					
Outcome Variable	**Case 1**	**Case 2**	**Case 3**	**Case 4**	**Case 5**	**Case 6**
Authenticity	.173	.376	.003**	.090	.030*	.019*
Cognitive strategies	.264	.947	.002**	.015*	.376	.615
Global score	.050	.610	.071	.158	.173	.316
Mental strain	.005**	.453	.981	.588	.008**	.554
I-PANAS-SF	.744	.099	.197	.202	.546	.921

*p < .05
**p < .01
***p < 0.001

Our regression analysis produced results that were mostly consistent across all virtual patient cases. The coefficients for the contrast between responses from the linear and branched virtual patient groups were not significant for any of the virtual patient cases. Each had a semi-partial correlation coefficient of 0.1 or less, meaning that the presence of decision-making elements within the case accounts for a very small proportion of the variance in reported self-efficacy. Removing the study arm from the model would have little impact upon its predictive power; ANOVA tests indicated that including the study arm variable did not significantly improve the model at the .05 level (Case 1: p=.63, Case 2: p=.18, Case 3: p=.68, Case 4: p=.24, Case 5: p=.32, Case 6: p=.63).

The largest contribution to the predictive power of the model was the institution, with values of ΔR^2 indicating that across the virtual patient cases institution accounted for between 17% and 50% of the variation in post-intervention self-efficacy. The pre-intervention self-efficacy rating had a significant coefficient for all cases at the .05 level, yet a relatively low semi-partial correlation coefficient at between 0.1 and 0.42. This is indicative of a lack of stability in the measure of pre-intervention self-efficacy and a wide variation within the model. The remaining variables of authenticity of patient encounter, cognitive strategies for the consultation, global score, mental strain and I-PANAS-SF score were also shown to account for very little of the variation in the model and have little predictive power in relation to post-intervention self-efficacy.

As an outcome, our findings showed that there was no evidence that the inclusion of decision-making elements in the form of branched or linear virtual patient designs had an impact upon learner self-efficacy or measures of their perceptions of the case authenticity, cognitive strategies, mental strain or affected states. Regardless of the inclusion of decision-making elements as a design feature of the virtual patient, learner self-efficacy increased. However, the institution in which a learner was enrolled did have a significant impact upon learner self-efficacy.

8 DISCUSSION

The aim of this thesis was to develop an improved understanding of how virtual patient design impacts upon undergraduate medical student learning when targeting medical error education. In order to achieve this we explored the impact of changing two of the key instructional design factors identified in the virtual patient design framework defined by Huwendiek et al. (Huwendiek, De Leng, et al., 2009): media and resources, and path type (i.e. linear or branching structure, or the inclusion of decision-making elements).

Within our studies, the remaining factors in the typology remained relatively constant; all virtual patients were delivered using the OpenLabyrinth system, were aimed at undergraduate medical students, and were delivered in small group teaching sessions of a common design and duration. In study I the intervention took place in the general problem-based learning curriculum, while in studies II-IV the intervention targeted medical error training in Paediatrics teaching. In studies II-IV we were required to deliver the interventions in different languages to reflect the local culture of participants.

8.1 USE OF VIDEO MEDIA

In study I we explored the use of video within virtual patients in the context of problem-based learning activities. We established that the use of video brought both positive and negative aspects to the learning activities. Although some learners felt that it made the scenarios feel more real, it also had the effect of making the learners observers in the scenario; they were watching the doctor in the videos as opposed to being cast in the role of the doctor. Accordingly, some learners felt that text helped to encourage their imagination. Although video was considered well suited to displaying procedures, it represented a challenge in the group dynamic of problem-based learning, slowing the pacing of the activity and preventing participants from reviewing the available information independently.

We concluded that an optimal approach would be to combine the two-modalities, relying predominantly on text, and using video only for elements where it has particular value. We also acknowledged requests from learners to provide text transcripts as alternatives to the videos, either concurrently or immediately following the first viewing of the video. Such a combination approach can be viewed through the cognitive theory of multimedia learning, which supposes that learners process information through dual channels, one auditory and one visual, each with a limited capacity (Mayer, 2009). Within the problem-based learning setting considered here, we are asking learners to process information from the following sources originating in the virtual patient resource: text (visual), images in the video (visual), and spoken word in the video (auditory). However, much of the learning in problem-based learning takes place through reflection in the group discussion (Norman & Schmidt, 1992); this is primarily spoken word (auditory) albeit with the normal visual cues associated with face-to-face conversation.

In this respect the timing of the elements of the activity becomes crucial; visual cues from the virtual patient in the form of text (and images) can be processed separately and therefore concurrently with the predominantly auditory information in the group discussion. When using video, both visual and auditory channels are engaged with that material and group discussion cannot take place. This not only demonstrates why the use of video inevitably slows the pace of the problem-based learning session, but also suggests why video might be best used for displaying procedures or similar. Such information is simply fact-based and serves as an exemplar with little need for group discussion, so is otherwise not well catered for by the problem-based learning approach which is recognised to be more suited for developing clinical skills than scientific knowledge (Albanese & Mitchell, 1993; Colliver, 2000; Norman & Schmidt, 2000).

8.2 PATH TYPE AND DECISION-MAKING ELEMENTS

Within the virtual patient design typology, a key instructional design factor identified was path type (Huwendiek, De Leng, et al., 2009). The authors identified two main path types, a linear string of pearls model, in which there is a pre-defined sequence that learners must follow, and a branching model in which learners can select from alternative routes with the possibility of different end points. The authors identified that this area of instructional design required more investigation to better understand its impact upon learners.

We explored the impact of different path types in studies II-IV by comparing interventions of two different path types, differentiated by the presence of decision-making elements on behalf of learners. In targeting medical error, the pathways taken in the virtual patient cases by both the linear and branching group included errors. Our approach to these studies was greatly informed by the perspective of Eva (2009), who considered whether educators should be “working to induce error in learners, leading them to short term pain for long term gain”. He states that “not only do we learn from our mistakes, but rather, mistakes are necessary evils when trying to induce learning”, and that more errors will occur in the long term if there is no opportunity to make errors while learning. In summary, his suggestion is that errors have significant pedagogic value, and that educators should seek to provide targeted opportunities for learners to make errors in order to allow them to reach their learning goals.

In our interventions, learners in both the linear and branched groups experienced errors, but the agency to be responsible for *making* errors was only available to the branching groups in which the virtual patient cases included decision-making elements. Based upon Eva’s perspective we hypothesised that these learners receiving branched virtual patients would demonstrate improved learning (i.e. long-term gain) but would experience increased mental strain, negative affected states and perhaps a reduction in self-efficacy (i.e. short-term pain). We anticipated that this may additionally impact upon their motivation and learning strategies. Our studies were therefore designed to measure these outcomes in order to better understand the interactions between them.

Our findings in study III demonstrated that improved learning took place with the virtual patient cases when compared with traditional didactic teaching methods. In particular, the branched virtual patients improved learning outcomes directly related to the decision points in the cases, though these did not transfer to settings beyond those decision points. This provided evidence of the “long-term gain” that we anticipated.

In contrast, studies II and IV provided no evidence of any “short-term pain” in the form of reduced self-efficacy, increased mental strain or negative affective states, nor any significant alteration in learner motivation. Despite our hypothesis, this is far from an undesirable outcome; if we can foster improved learning outcomes without learners experiencing any negative impact then this might be considered an ideal situation. Nevertheless, given these results we would like to better understand the learning process experienced by the students in our trial.

One possible explanation for our findings is that there simply was no negative impact for students of making decisions and consequently errors in the cases. The potential for a negative impact on learners is reduced by the learning activities being well-designed. As understood when viewed through the lens of the cognitive theory of multimedia learning (Mayer, 2009), our intervention seeks to encourage generative cognitive processing on behalf of the learner in order to make sense of the material, while minimising extraneous cognitive processing as a principle of sound instructional design (Mayer & Moreno, 2003). This is in part achieved through the use of patient cases as worked examples, a technique known to reduce extraneous processing (Young et al., 2014). As an outcome of study I, the use of text as a media type was specifically selected to reduce the provision of redundant information and make the materials easier to review (Woodham et al., 2015), in adherence with Mayer and Moreno’s redundancy principle for reducing extraneous cognitive load. The perceptions of simulations such as virtual patients being a safe space in which there are no real-life consequences for patients (Ziv et al., 2005; Ziv, Wolpe, Small, & Glick, 2003) also has the potential to reduce any negative impact of making errors within the resources.

However, one other possible explanation is that any negative impact had dissipated by the time that our outcome measures were taken. It is a limitation of our study design that our enquiry was of the learners’ self-report rating of the outcome measures either after the virtual patient case, or the series of virtual patient cases, has concluded. This limited the judgements that we can make about the learners’ experience during the interventions. While negative affected states such as confusion may result from making errors, they can be beneficial for learning providing that they are resolved (D’Mello, Lehman, Pekrun, & Graesser, 2014). Given that the virtual patient cases were designed to provide feedback through a narrative that reached an end point, any confusion on the part of learners may have been resolved and therefore not accurately reflected in our post-intervention outcome measures. Lehman, D’Mello and Graesser (2012) have also commented on the limits to self-report measures of confusion, caused by learner unwillingness to accurately represent these emotions and it is possible to consider that these same challenges may also apply to expressions of negative impact here.

Finally, it is also possible that any negative impact of decision-making was also mitigated by the group dynamic in the teaching sessions i.e. the sense that no individual was responsible for errors in decision-making, thus reducing any negative impact. Laurillard describes collaborative learning as distinct from learning through practice, since the process is about negotiation of a shared outcome with one's peers (Laurillard, 2013). This negotiation ultimately results in a shared responsibility for the decisions taken, which has the potential to reduce the impact of any error made from an individual perspective.

It is clear that the interactions between negative affected states, mental strain, self-efficacy and motivation are both complex and time-bound, such that we cannot hope to fully understand them through quantitative outcome measures alone. Further qualitative work would allow us to better understand these interactions from the perspective of the learner (Tavakol & Sandars, 2014). Approaches such as phenomenology are designed to understand lived experiences from the perspective of a small number of subjects (Creswell, 2002, 2012) and have previously been applied to virtual patients in self-directed learning settings (Edelbring et al., 2011). Alternatively, research approaches such as realist evaluation acknowledge the complexity of interacting factors in real-world interventions, and are suitable for establishing a greater understanding of the findings of comparative trials and quantitative studies (Wong, Greenhalgh, Westhorp, & Pawson, 2012).

8.2.1 Transfer of learning

Although our findings in study III indicate improved learning took place as a result of the virtual patient interventions, and in particular where related to the decision points in the branched variants, there was no evidence that this transferred to other settings. Perkins and Salomon (2012) describe transfer as an intrinsic part of learning, and that evidence of learning requires learners to be able to replicate something at a later time and in another set of conditions. Although learners have been able to demonstrate learning in our study through their performance in the single-best answer assessment, they have not done so where the conditions being assessed differed from those in the virtual patient. This is indicative of the "failure-to-transfer" phenomenon identified by Chi and VanLehn (2012), in which learners only perform well at tasks when they are directly recognisable from prior learning (i.e. the surface features are similar). This results from a failure to recognise that the deeper structures, or the underlying characteristics of a problem, can be similar such that prior learning will apply even if superficially the tasks appear to be different.

In seeking to understand why this has occurred in our study, it is helpful to consider the stages of Kolb's experiential learning cycle (Kolb, 1984; Yardley et al., 2012). The process of identifying similarities in the deeper structures of a task might be considered to be a consequence of the abstract conceptualisation phase of the cycle, in which learners extract learning from their experiences and build cognitive models that transform to other settings.

The failure of learners in this study to do this suggests that this phase of the experiential learning cycle has not been adequately supported in the learning activities designed. The process of concrete experience is directly provided by the virtual patient resources, while the process of reflective observation is facilitated by collaborative learning in the problem-based learning group setting (Ellaway et al., 2015; Norman, 1988). Learners are able to undertake the active experimentation phase through exposure to the clinical environment and further virtual patient cases, but our designed learning experience does not directly facilitate active conceptualisation.

When designing a learning experience it is essential to consider the activity holistically rather than as simply a digital resource (Ellaway, 2014). For future work, we must consider how best a learning activity based upon virtual patients can be designed to provide students with the means to engage in abstract conceptualisation, and to explore the subsequent impact upon learning transfer to new settings.

8.3 METHODOLOGICAL CONSIDERATIONS

The research methodology chosen for this project and its constituent studies was influenced primarily by the nature of the research questions, as well as the practical realities of running such studies across multiple centres and using multiple languages. The geographically and culturally disparate nature of the participants in the studies limited the choice of study design and introduced some limitations, but overall provided positive factors by allowing studies to be repeated across multiple institutions.

A key strength of the studies in this thesis was that they were exploring interventions that were embedded directly into and experienced within the taught curricula of undergraduate medical students. This had the benefit of avoiding a risk of volunteer bias since all students in the cohort receive the intervention and are not a self-selecting group, although it also increases the risk of response bias from participants who fear that an unfavourable response might affect their grade. We mitigated against this by obtaining consent for the completion of outcome measures rather than the intervention, and by comparing two different interventions so that there was no clear control group from the participants perspective. Our study design comparing two interventions is also supported in the literature which argues that there is no value in comparisons with a no-intervention control group (Cook, 2012a).

Having delivered the interventions within the curriculum, we can learn from the literature around evaluating educational programmes. Cook (2010b) describes three possible approaches to programme evaluations. The process-oriented approach takes a comprehensive view of the development of a programme, while the participant-oriented approach typically uses qualitative methods to focus on the experiences of the learner. These methods hold significant complexity, and have limitations related to cost, flexibility and generalisability. This project takes an objectives-oriented approach, examining outcomes against instructional goals with predetermined research questions. Although evaluations of this type are unable to capture unexpected developments, they are able to focus directly on the research questions using a relatively simple design. This simplicity allowed us to develop on another strength of the studies, which took place at multiple centres. Our study design incorporated participants at six different institutions across studies II-IV, allowing us to show repeated effects at all sites and providing evidence for the generalisability of our findings to other institutional settings.

However, the practical challenges of delivering a controlled comparative study design at multiple sites also resulted in significant limitations to our studies. The complexity of controlling data collection and recruitment at multiple sites in studies II-IV meant that we were unable to report precise figures for the potential size of cohorts, participants recruited, or response rates, instead only reporting numbers completing outcome measures. This challenge was manifested by the failure of one site to deliver complete data sets in a timely fashion in study III leading to their exclusion from the study, and a greater than expected number of responses being received from some institutions in study IV without adequate explanation. A consequence of this is that we are not fully able to assess the risk of attrition or reporting bias in our studies, and whether there may have been a systematic difference between the participants completing outcome measures or otherwise. It is however a virtue of our repeated study design across several centres that the impact of such bias on our findings would likely be limited to specific institutions.

Another limitation resulted from the use of pre-existing teaching groups at each of the institutions in studies II-IV. As a consequence of using groups to which students were already allocated, we were unable to randomly allocate individual students to different study arms. Instead, clusters were randomised to each of the study arms, even though results were reported individually.

This challenge was compounded by the ethical and practical difficulties that ensured survey responses must remain anonymous, meaning that we could neither identify individuals or the small teaching groups to which students belonged. This has the potential to result in intra-class correlation and within-group agreement, resulting from a tendency for responses from within a group to reflect a general agreement and similar scores (Bliese, 2000). Without information about individual responses we were unable to control for this through statistical methods, giving the potential for this effect to impact upon our findings. With the benefit of both hindsight and more experience, we would have benefitted from putting in place a system for pseudonymising responses. This would have allowed us to both control for intra-class correlation, and to adopt repeated-measures analytic approaches that could have strengthened our findings. That being said, language barriers and geographical distance would have the potential to make implementing this additional complexity extremely challenging, with a heightened risk of data being incorrectly collected or reported.

Although our randomisation procedures and lack of control for intra-class clustering represent study limitations, there is evidence in the literature that disputes the importance of these effects. Cook (2012b) and Norman (2003) both argue that randomisation alone does not equate with strong methods, given the number of confounders in educational research. Bliese (2000) establishes that the probable impact of intra-class correlation is to exaggerate differences between groups; since our results in studies II and IV showed that there was no significant difference between groups we can interpret that any effect of this intra-class correlation on our data has not impacted upon our findings.

Ultimately, our research focus on the impact of virtual patient design on the learner experience could have motivated the use of a greater level of qualitative enquiry in our studies. These methods could certainly have yielded additional insights into the complex interactions of the constructs being explored, and the impact of the many confounding variables that are inevitable in within-curriculum educational research. In particular, observational studies might have allowed us to explore the group dynamics and the interactions with facilitators in the teaching sessions which have a crucial role in the learning process. However, the complexity of these methods and their implementation, not to mention language and cultural barriers, would not have allowed us to complete these studies across multiple sites, and may therefore lack transferability beyond the individual contexts under examination. The use of qualitative methods would be suitable for use in further work in specific contexts, particularly for research aimed at building theory which could guide a greater understanding of the cognitive processes taking place when using interventions of this type.

9 CONCLUSIONS

The overarching research question for the project was “How can virtual patients be designed to support student learning around medical error?” We have demonstrated that virtual patients can support improved student learning around medical error, and that using a branched decision-making design does not result in a negative impact upon learner motivation or self-efficacy once the activity is concluded. These results have been shown to hold across a number of cultural settings and institutions where the educational approach of small-group teaching has remained constant. Within the context of one institution, the use of video has been shown to be problematic in the small-group teaching setting but has value for embedding specific learning activities such as observing exemplars of procedures. However, improved learning around the decision-making elements in a branched virtual patient design was limited to areas with similar surface features.

9.1 IMPLICATIONS

A recent review article called for more research into design variants of virtual patients to better inform the design of learning activities (Kononowicz et al., 2019). This thesis aims to provide more evidence to guide such designs in future, particularly in the context of medical error education. The findings suggest that educators should seek to design activities that allow learners to rehearse key patient management decisions, and that these should use branched decision-making elements within virtual patients to provide a safe environment for this to take place. However, educators must also design complementary learning activities that allow learners to engage in abstract conceptualisation such that they can recognise deeper features within their learning and transfer these to other settings.

From a research perspective, it is clear that the limitation to our study of being unable to identify individual learners has limited the power of the insights that we are able to derive from this work. This limitation indicates that researchers should design experiments of this type in such a way that repeated measure designs can be used to track learner progress, draw additional conclusions and control for within-group clustering effects. However, through our work we have demonstrated the feasibility of running a comparative research design across several centres, and that this has the potential to demonstrate the generalisability of our findings.

9.2 FUTURE WORK

We would encourage future research to explore these findings not only in different cultural settings, but also in other educational approaches. Virtual patients are commonly used for self-directed learning, and there is a need to better understand the impact on motivation and self-efficacy of making errors in a virtual patient when these are the responsibility of an individual and not moderated by a collaborative group.

The learning process is a complex one, and the relationships between self-efficacy, learner motivation and factors such as mental strain and affected states are variable and specific to individuals. The future use of qualitative methods to explore these interactions in more detail would help us to develop a greater understanding of the process of learning using virtual patients and help us to better formulate and guide hypotheses about the variation of other virtual patient design features not explored here.

10 EPILOGUE

In the prologue to this thesis, I discussed how I came to be working in medical education and to have undertaken doctoral studies. I started as a technologist, and over time developed a passion for education and the application of technology in the creation of improved learner experiences. My doctoral studies and the development of this thesis have been even more transformative. The journey has impacted upon my life as a professional and as a person, and has fundamentally shifted my view of research.

Before my studies began, I believed I understood what was meant by research. I understood that research began with a question for which an answer was needed, and that researchers devised experiments which hoped to answer such questions. Through the education I have received at Karolinska Institutet, I now know that research is so much richer and more complex than I understood at the time.

I have learnt about the nature of ontology and epistemology, and how this can shape the way in which researchers see the world. I have come to appreciate the value of using theory to guide research, and the clarity that this can bring when interpreting our results. I am more aware of the importance of the context in which we carry out research, and the limitations that there might be to the generalisability of our findings.

Most of all, I have had the opportunity to develop an appreciation for the complex questions and ideas that can be explored through qualitative methods, and what this can bring to mixed-methods study designs. I have a deeper understanding of the importance of reflexivity in researchers, and ways in which the transferability of the findings resulting from qualitative research can be considered.

My hope and objective is to continue to use the education that I have received to transform and develop my practice as a researcher and as a learning technologist, and to contribute to improved learning experiences that support the extraordinary service which medical and healthcare trainees and professionals provide to society.

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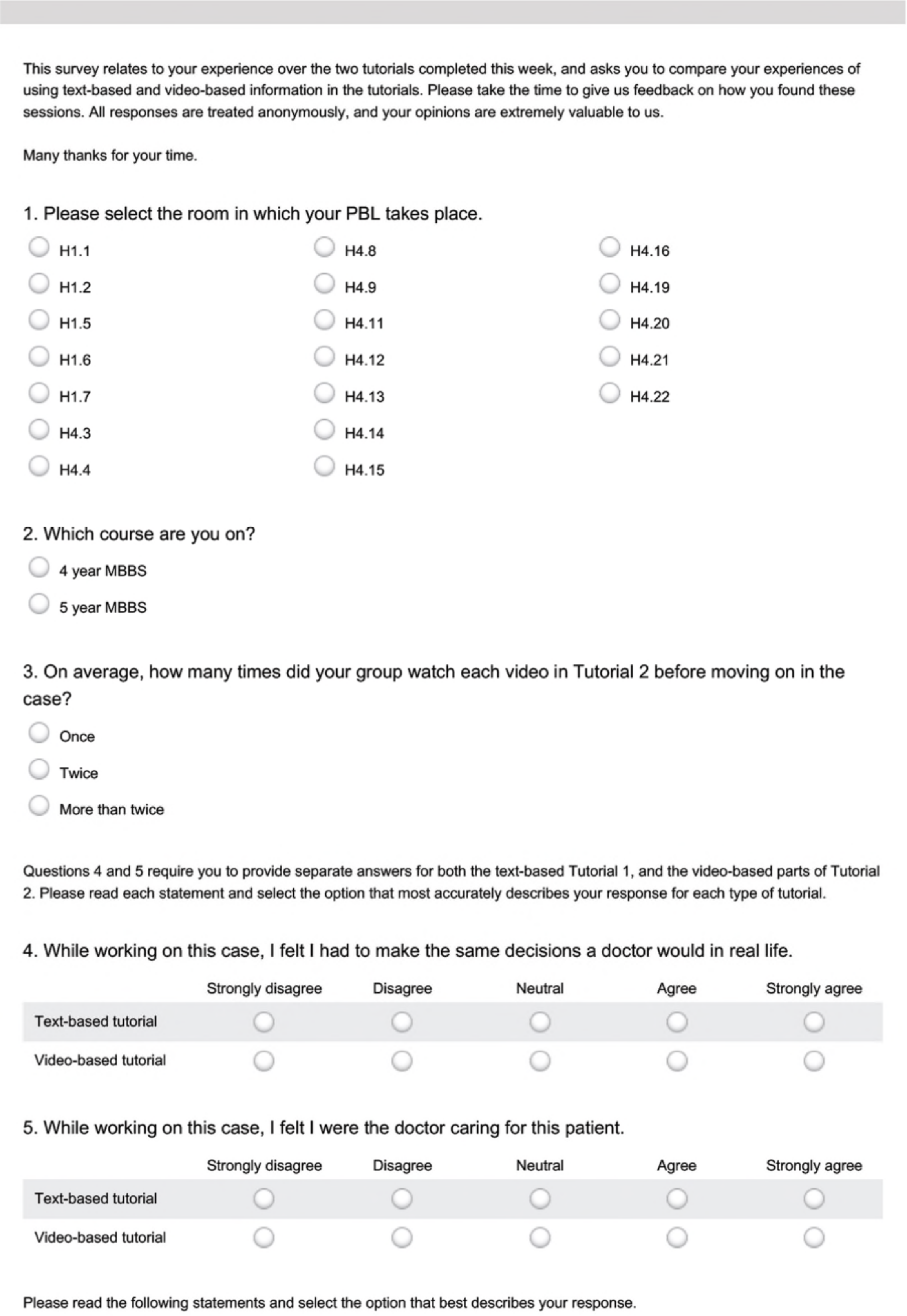
APPENDIX 1 STUDY I - STUDENT SURVEY INSTRUMENT



This survey relates to your experience over the two tutorials completed this week, and asks you to compare your experiences of using text-based and video-based information in the tutorials. Please take the time to give us feedback on how you found these sessions. All responses are treated anonymously, and your opinions are extremely valuable to us.

Many thanks for your time.

1. Please select the room in which your PBL takes place.

- ○ H1.1
- ○ H1.2
- ○ H1.5
- ○ H1.6
- ○ H1.7
- ○ H4.3
- ○ H4.4
- ○ H4.8
- ○ H4.9
- ○ H4.11
- ○ H4.12
- ○ H4.13
- ○ H4.14
- ○ H4.15
- ○ H4.16
- ○ H4.19
- ○ H4.20
- ○ H4.21
- ○ H4.22

2. Which course are you on?

- ○ 4 year MBBS
- ○ 5 year MBBS

3. On average, how many times did your group watch each video in Tutorial 2 before moving on in the case?

- ○ Once
- ○ Twice
- ○ More than twice

Questions 4 and 5 require you to provide separate answers for both the text-based Tutorial 1, and the video-based parts of Tutorial 2. Please read each statement and select the option that most accurately describes your response for each type of tutorial.

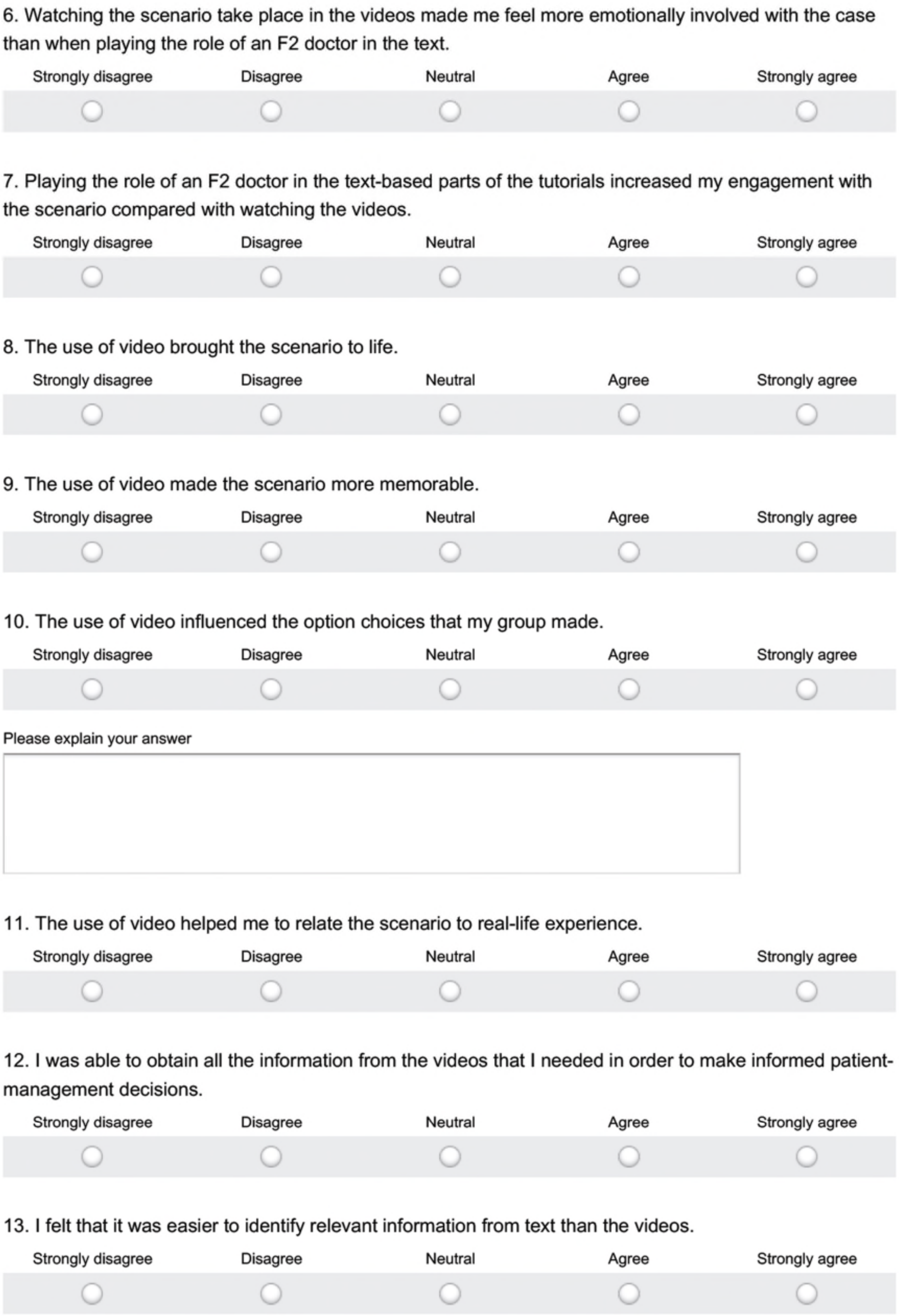
4. While working on this case, I felt I had to make the same decisions a doctor would in real life.

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
Text-based tutorial	○	○	○	○	○
Video-based tutorial	○	○	○	○	○

5. While working on this case, I felt I were the doctor caring for this patient.

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
Text-based tutorial	○	○	○	○	○
Video-based tutorial	○	○	○	○	○

Please read the following statements and select the option that best describes your response.



6. Watching the scenario take place in the videos made me feel more emotionally involved with the case than when playing the role of an F2 doctor in the text.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

7. Playing the role of an F2 doctor in the text-based parts of the tutorials increased my engagement with the scenario compared with watching the videos.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

8. The use of video brought the scenario to life.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

9. The use of video made the scenario more memorable.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

10. The use of video influenced the option choices that my group made.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

Please explain your answer

11. The use of video helped me to relate the scenario to real-life experience.

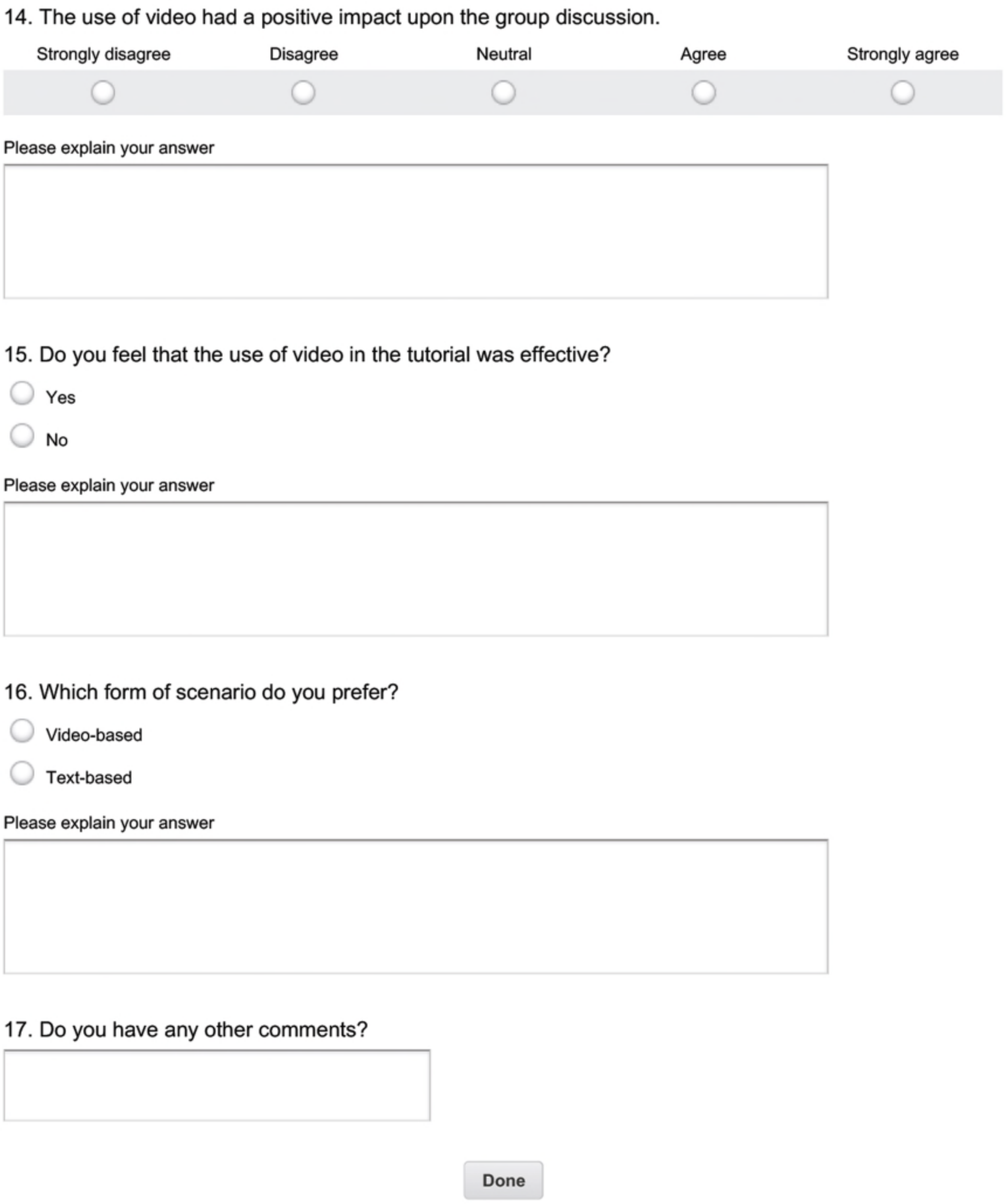
Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

12. I was able to obtain all the information from the videos that I needed in order to make informed patient-management decisions.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

13. I felt that it was easier to identify relevant information from text than the videos.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○



14. The use of video had a positive impact upon the group discussion.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

Please explain your answer

15. Do you feel that the use of video in the tutorial was effective?

○ Yes

○ No

Please explain your answer

16. Which form of scenario do you prefer?

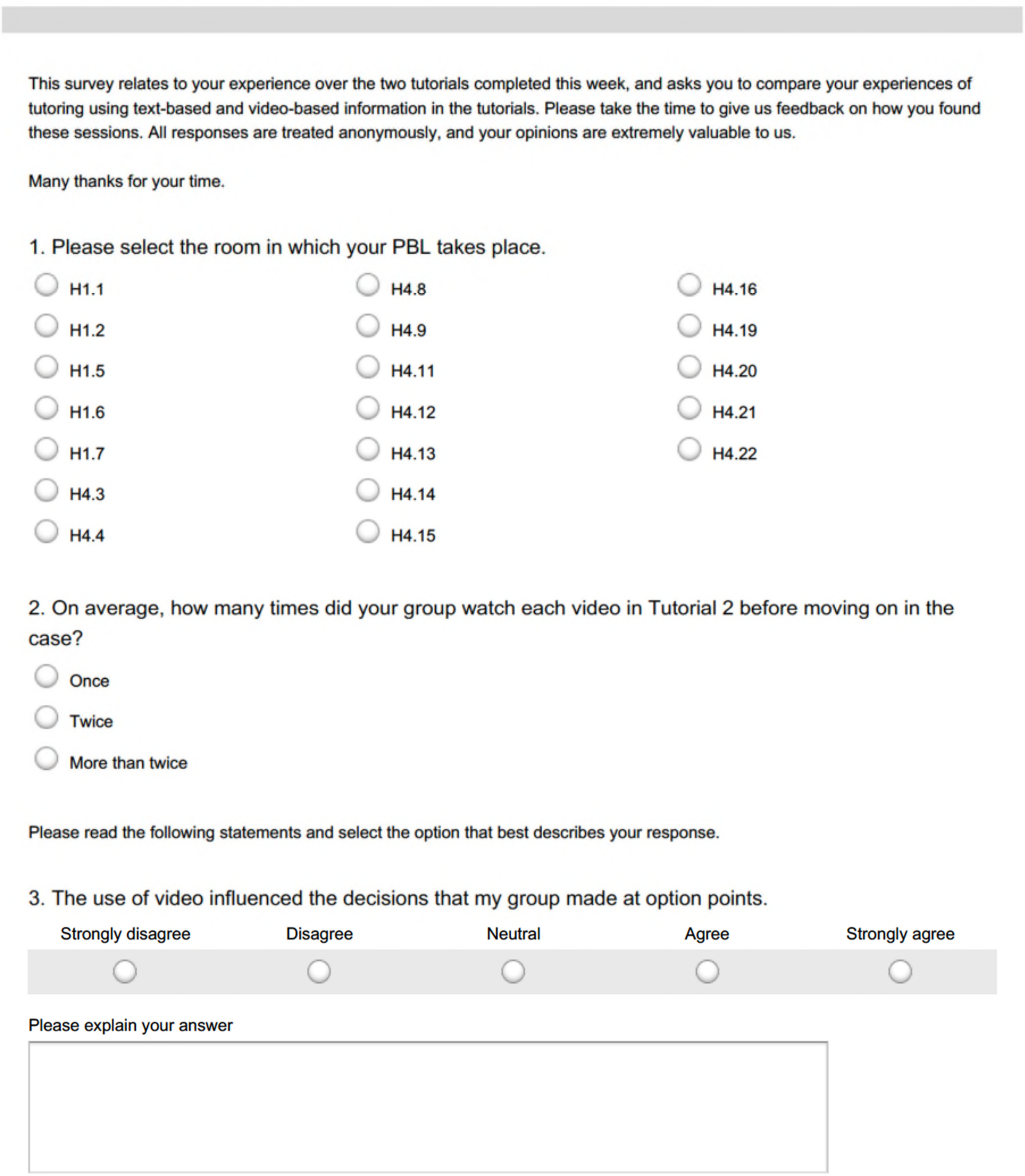
○ Video-based

○ Text-based

Please explain your answer

17. Do you have any other comments?

APPENDIX 2 STUDY I - TUTOR SURVEY INSTRUMENT



This survey relates to your experience over the two tutorials completed this week, and asks you to compare your experiences of tutoring using text-based and video-based information in the tutorials. Please take the time to give us feedback on how you found these sessions. All responses are treated anonymously, and your opinions are extremely valuable to us.

Many thanks for your time.

1. Please select the room in which your PBL takes place.

○ H1.1
○ H1.2
○ H1.5
○ H1.6
○ H1.7
○ H4.3
○ H4.4
○ H4.8
○ H4.9
○ H4.11
○ H4.12
○ H4.13
○ H4.14
○ H4.15
○ H4.16
○ H4.19
○ H4.20
○ H4.21
○ H4.22

2. On average, how many times did your group watch each video in Tutorial 2 before moving on in the case?

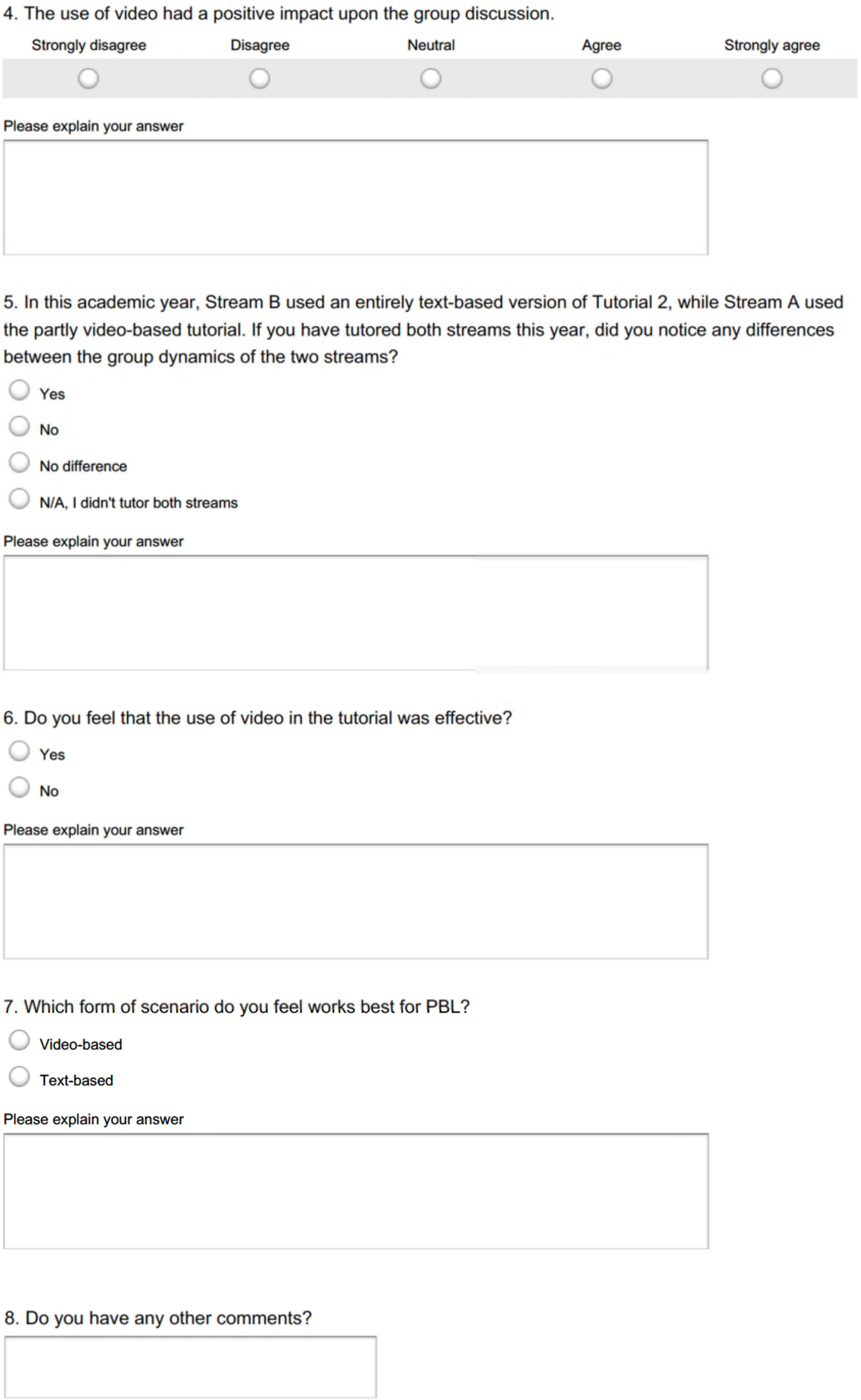
○ Once
○ Twice
○ More than twice

Please read the following statements and select the option that best describes your response.

3. The use of video influenced the decisions that my group made at option points.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

Please explain your answer



4. The use of video had a positive impact upon the group discussion.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

Please explain your answer

5. In this academic year, Stream B used an entirely text-based version of Tutorial 2, while Stream A used the partly video-based tutorial. If you have tutored both streams this year, did you notice any differences between the group dynamics of the two streams?

○ Yes
○ No
○ No difference
○ N/A, I didn't tutor both streams

Please explain your answer

6. Do you feel that the use of video in the tutorial was effective?

○ Yes
○ No

Please explain your answer

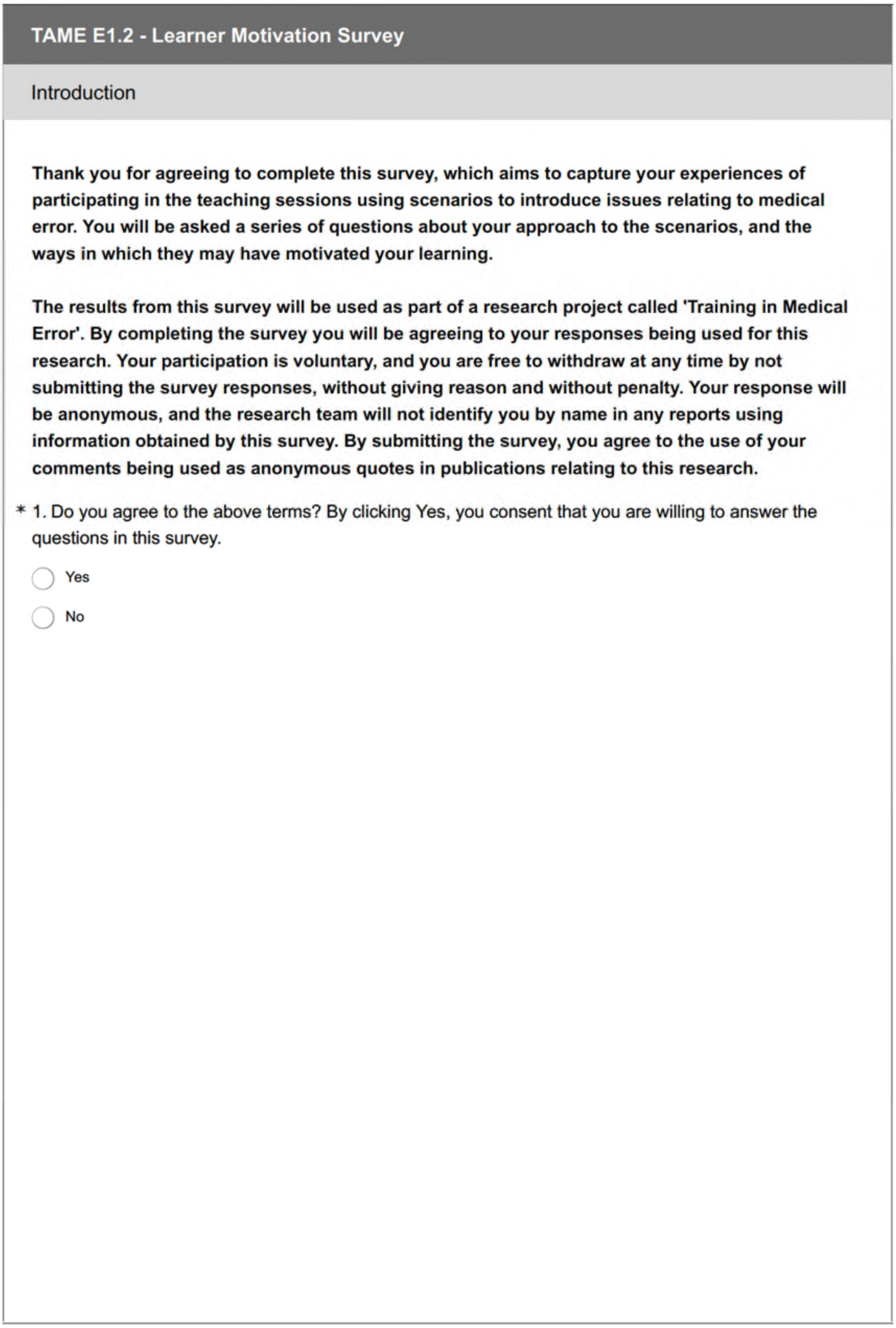
7. Which form of scenario do you feel works best for PBL?

○ Video-based
○ Text-based

Please explain your answer

8. Do you have any other comments?

APPENDIX 3 STUDY II - SURVEY INSTRUMENT



TAME E1.2 - Learner Motivation Survey

Introduction

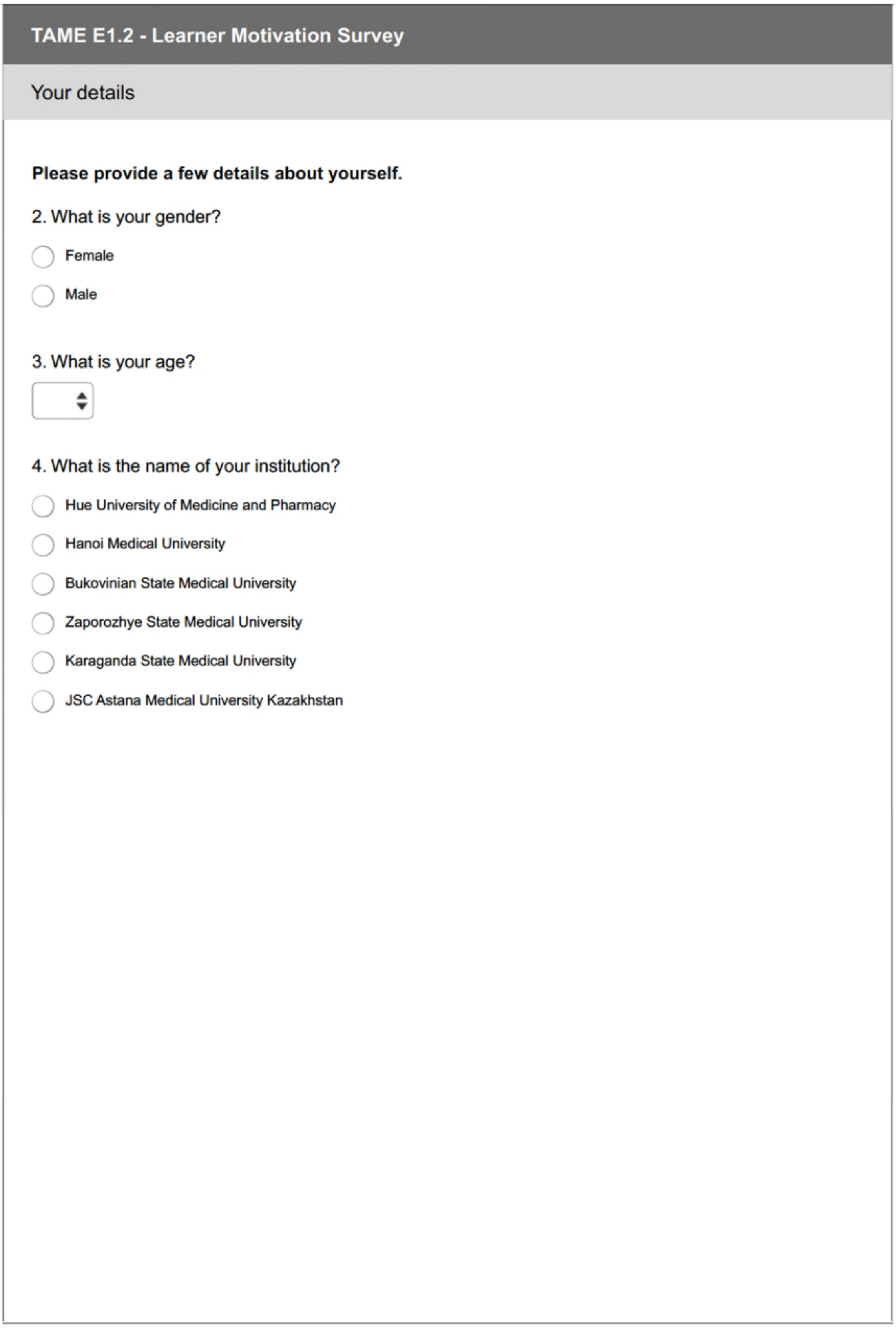
Thank you for agreeing to complete this survey, which aims to capture your experiences of participating in the teaching sessions using scenarios to introduce issues relating to medical error. You will be asked a series of questions about your approach to the scenarios, and the ways in which they may have motivated your learning.

The results from this survey will be used as part of a research project called 'Training in Medical Error'. By completing the survey you will be agreeing to your responses being used for this research. Your participation is voluntary, and you are free to withdraw at any time by not submitting the survey responses, without giving reason and without penalty. Your response will be anonymous, and the research team will not identify you by name in any reports using information obtained by this survey. By submitting the survey, you agree to the use of your comments being used as anonymous quotes in publications relating to this research.

* 1. Do you agree to the above terms? By clicking Yes, you consent that you are willing to answer the questions in this survey.

○ Yes

○ No



TAME E1.2 - Learner Motivation Survey

Your details

Please provide a few details about yourself.

2. What is your gender?

○ Female

○ Male

3. What is your age?

4. What is the name of your institution?

○ Hue University of Medicine and Pharmacy

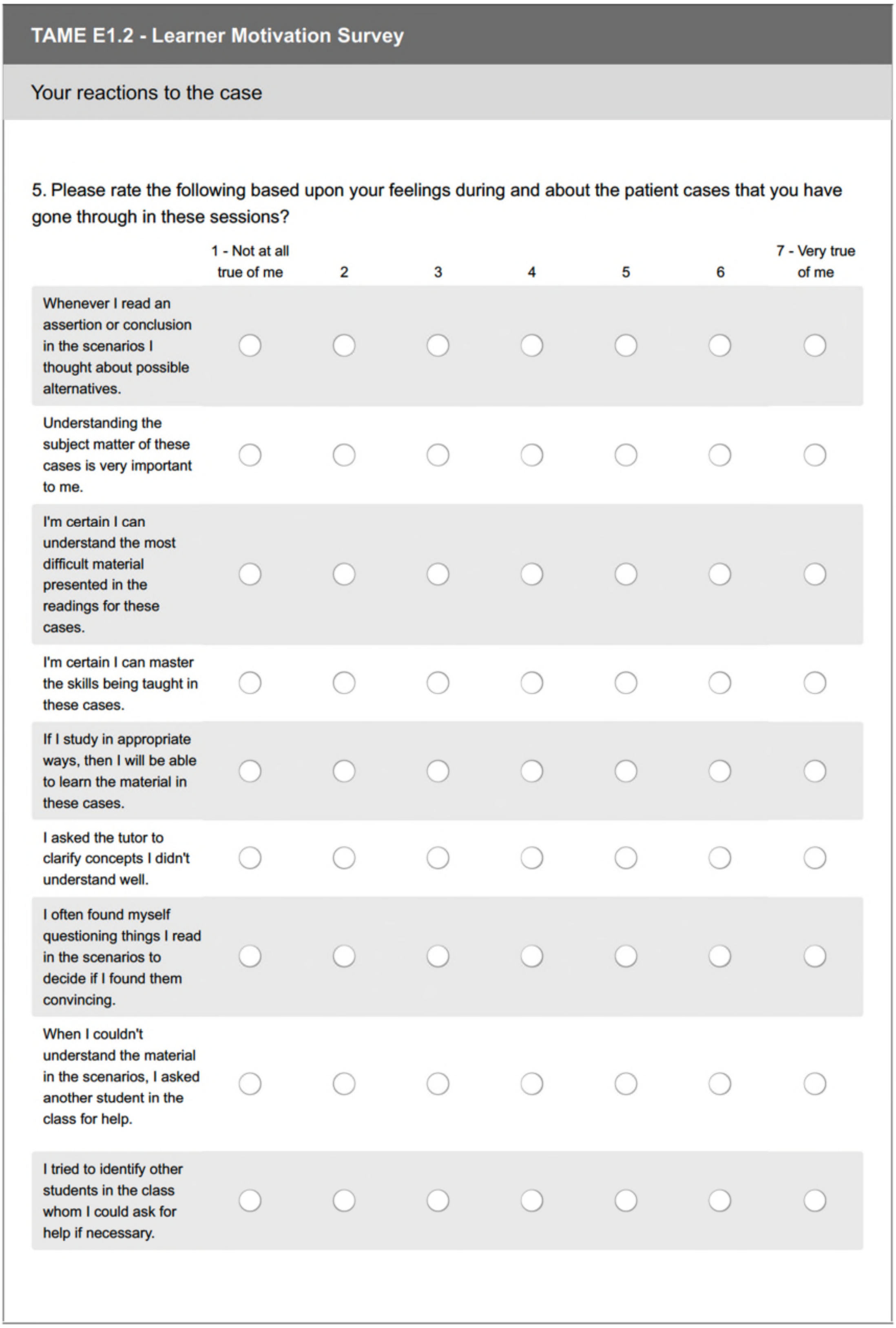
○ Hanoi Medical University

○ Bukovinian State Medical University

○ Zaporozhye State Medical University

○ Karaganda State Medical University

○ JSC Astana Medical University Kazakhstan

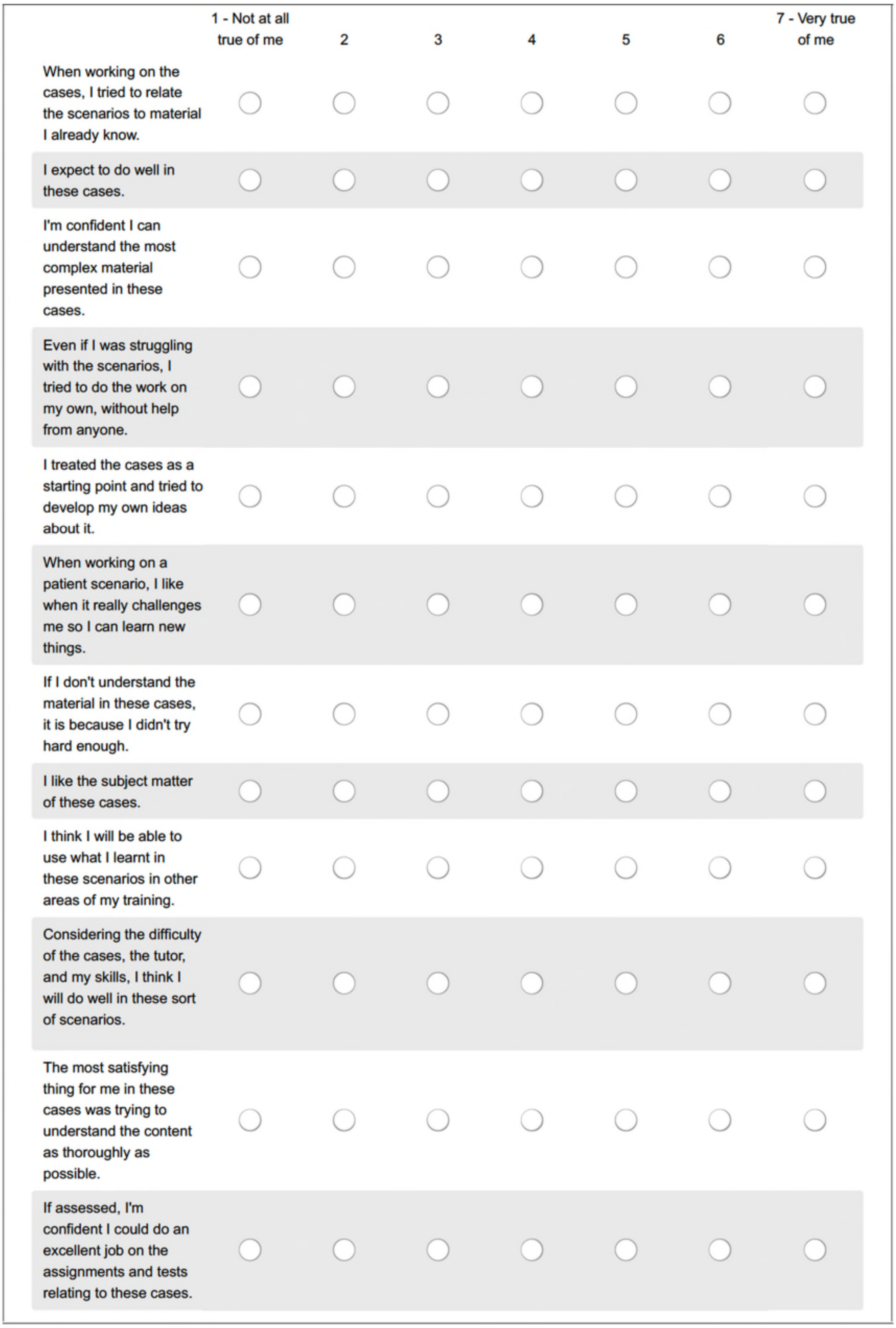


TAME E1.2 - Learner Motivation Survey

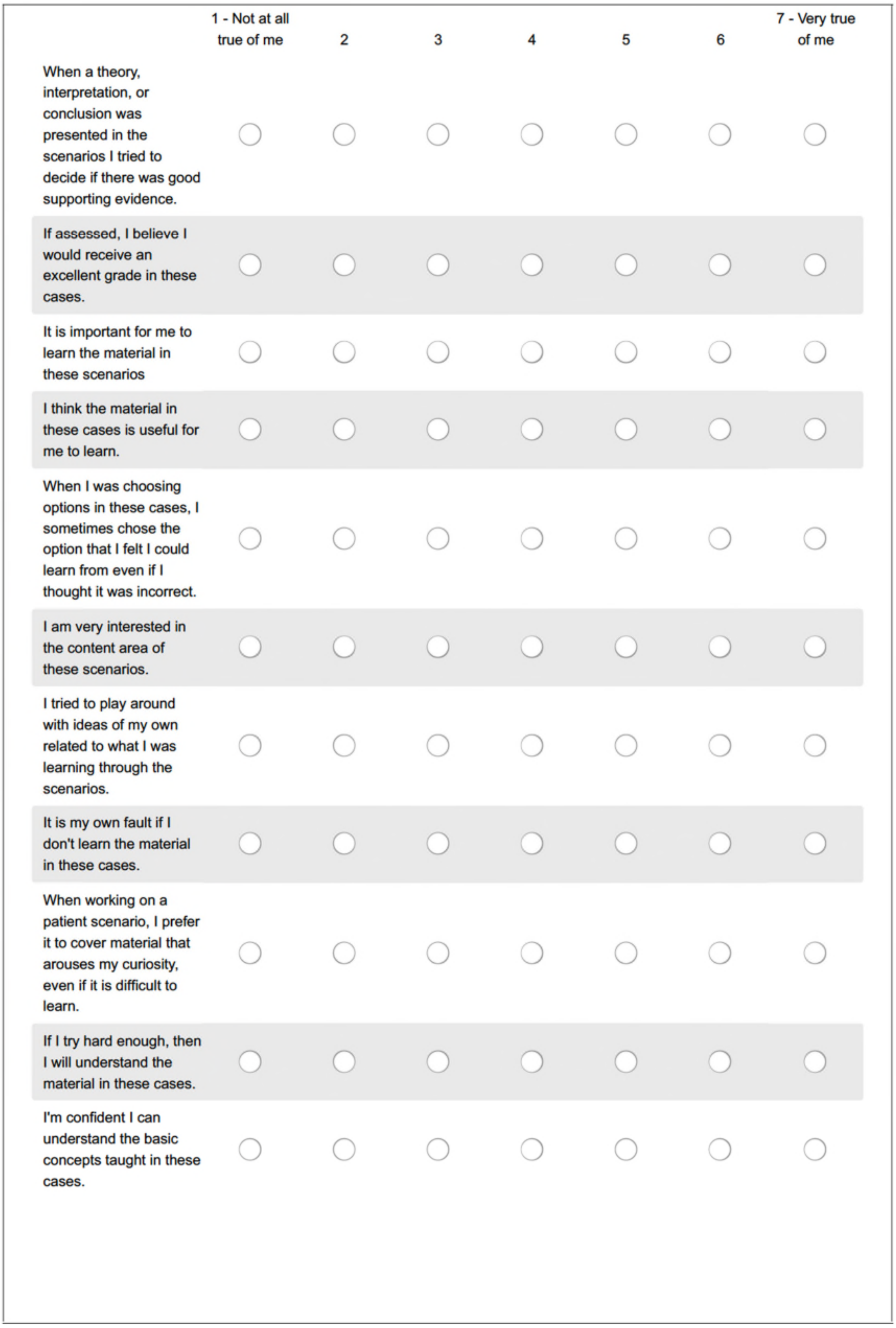
Your reactions to the case

5. Please rate the following based upon your feelings during and about the patient cases that you have gone through in these sessions?

	1 - Not at all true of me	2	3	4	5	6	7 - Very true of me
Whenever I read an assertion or conclusion in the scenarios I thought about possible alternatives.	○	○	○	○	○	○	○
Understanding the subject matter of these cases is very important to me.	○	○	○	○	○	○	○
I'm certain I can understand the most difficult material presented in the readings for these cases.	○	○	○	○	○	○	○
I'm certain I can master the skills being taught in these cases.	○	○	○	○	○	○	○
If I study in appropriate ways, then I will be able to learn the material in these cases.	○	○	○	○	○	○	○
I asked the tutor to clarify concepts I didn't understand well.	○	○	○	○	○	○	○
I often found myself questioning things I read in the scenarios to decide if I found them convincing.	○	○	○	○	○	○	○
When I couldn't understand the material in the scenarios, I asked another student in the class for help.	○	○	○	○	○	○	○
I tried to identify other students in the class whom I could ask for help if necessary.	○	○	○	○	○	○	○

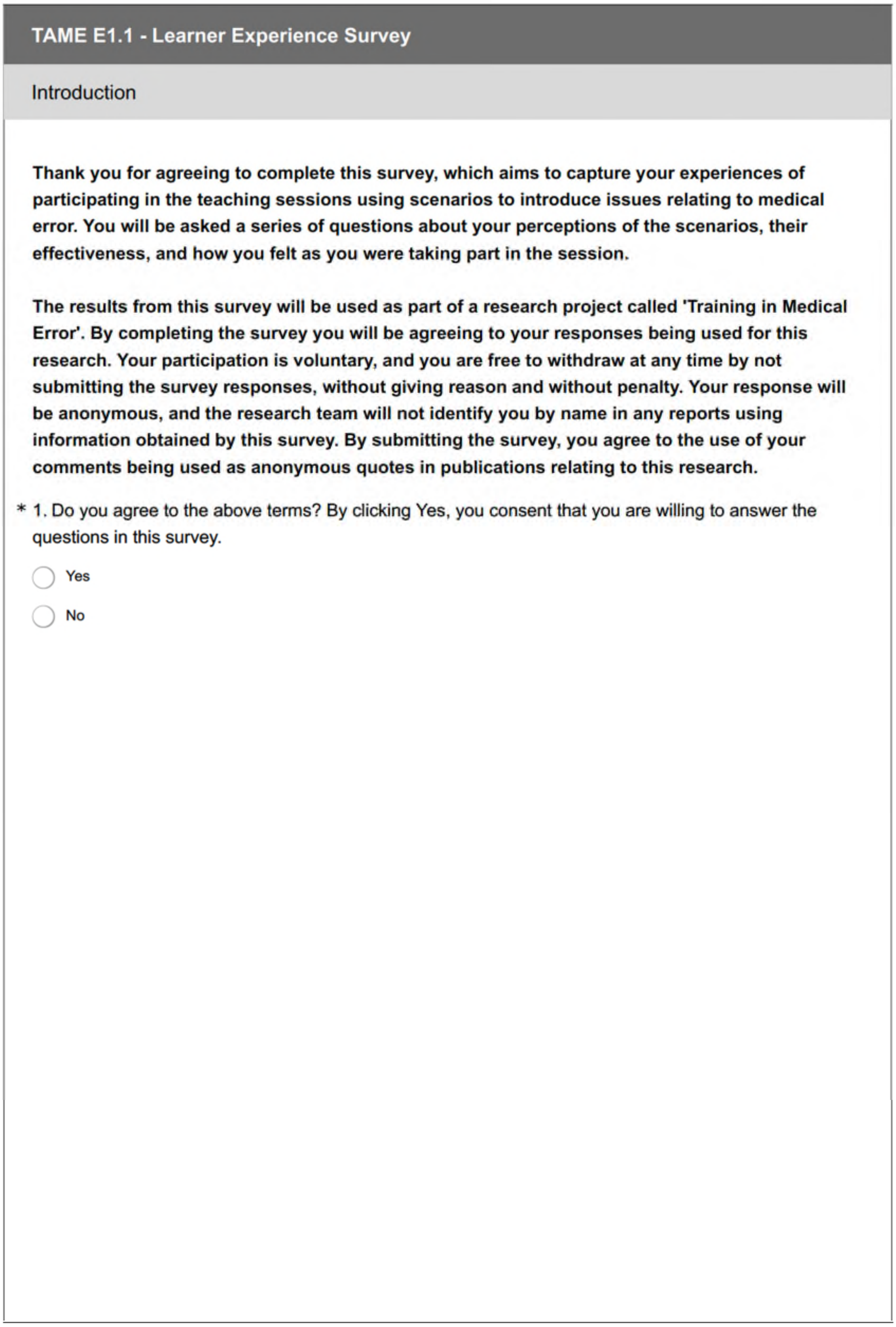


	1 - Not at all true of me	2	3	4	5	6	7 - Very true of me
When working on the cases, I tried to relate the scenarios to material I already know.	○	○	○	○	○	○	○
I expect to do well in these cases.	○	○	○	○	○	○	○
I'm confident I can understand the most complex material presented in these cases.	○	○	○	○	○	○	○
Even if I was struggling with the scenarios, I tried to do the work on my own, without help from anyone.	○	○	○	○	○	○	○
I treated the cases as a starting point and tried to develop my own ideas about it.	○	○	○	○	○	○	○
When working on a patient scenario, I like when it really challenges me so I can learn new things.	○	○	○	○	○	○	○
If I don't understand the material in these cases, it is because I didn't try hard enough.	○	○	○	○	○	○	○
I like the subject matter of these cases.	○	○	○	○	○	○	○
I think I will be able to use what I learnt in these scenarios in other areas of my training.	○	○	○	○	○	○	○
Considering the difficulty of the cases, the tutor, and my skills, I think I will do well in these sort of scenarios.	○	○	○	○	○	○	○
The most satisfying thing for me in these cases was trying to understand the content as thoroughly as possible.	○	○	○	○	○	○	○
If assessed, I'm confident I could do an excellent job on the assignments and tests relating to these cases.	○	○	○	○	○	○	○



	1 - Not at all true of me	2	3	4	5	6	7 - Very true of me
When a theory, interpretation, or conclusion was presented in the scenarios I tried to decide if there was good supporting evidence.	○	○	○	○	○	○	○
If assessed, I believe I would receive an excellent grade in these cases.	○	○	○	○	○	○	○
It is important for me to learn the material in these scenarios	○	○	○	○	○	○	○
I think the material in these cases is useful for me to learn.	○	○	○	○	○	○	○
When I was choosing options in these cases, I sometimes chose the option that I felt I could learn from even if I thought it was incorrect.	○	○	○	○	○	○	○
I am very interested in the content area of these scenarios.	○	○	○	○	○	○	○
I tried to play around with ideas of my own related to what I was learning through the scenarios.	○	○	○	○	○	○	○
It is my own fault if I don't learn the material in these cases.	○	○	○	○	○	○	○
When working on a patient scenario, I prefer it to cover material that arouses my curiosity, even if it is difficult to learn.	○	○	○	○	○	○	○
If I try hard enough, then I will understand the material in these cases.	○	○	○	○	○	○	○
I'm confident I can understand the basic concepts taught in these cases.	○	○	○	○	○	○	○

APPENDIX 4 STUDY IV - SURVEY INSTRUMENT



TAME E1.1 - Learner Experience Survey

Introduction

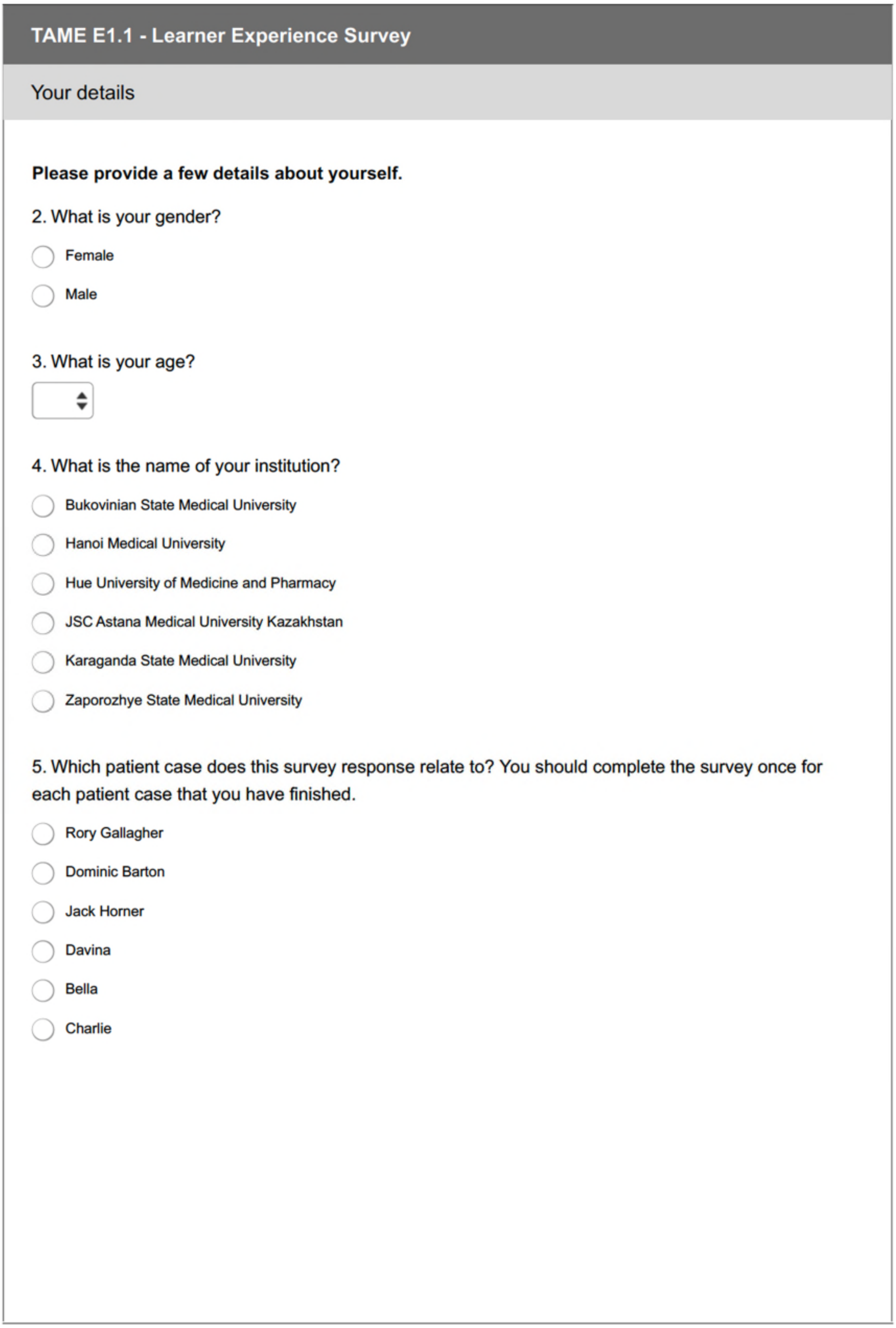
Thank you for agreeing to complete this survey, which aims to capture your experiences of participating in the teaching sessions using scenarios to introduce issues relating to medical error. You will be asked a series of questions about your perceptions of the scenarios, their effectiveness, and how you felt as you were taking part in the session.

The results from this survey will be used as part of a research project called 'Training in Medical Error'. By completing the survey you will be agreeing to your responses being used for this research. Your participation is voluntary, and you are free to withdraw at any time by not submitting the survey responses, without giving reason and without penalty. Your response will be anonymous, and the research team will not identify you by name in any reports using information obtained by this survey. By submitting the survey, you agree to the use of your comments being used as anonymous quotes in publications relating to this research.

* 1. Do you agree to the above terms? By clicking Yes, you consent that you are willing to answer the questions in this survey.

○ Yes

○ No



TAME E1.1 - Learner Experience Survey

Your details

Please provide a few details about yourself.

2. What is your gender?

○ Female

○ Male

3. What is your age?

4. What is the name of your institution?

○ Bukovinian State Medical University

○ Hanoi Medical University

○ Hue University of Medicine and Pharmacy

○ JSC Astana Medical University Kazakhstan

○ Karaganda State Medical University

○ Zaporozhye State Medical University

5. Which patient case does this survey response relate to? You should complete the survey once for each patient case that you have finished.

○ Rory Gallagher

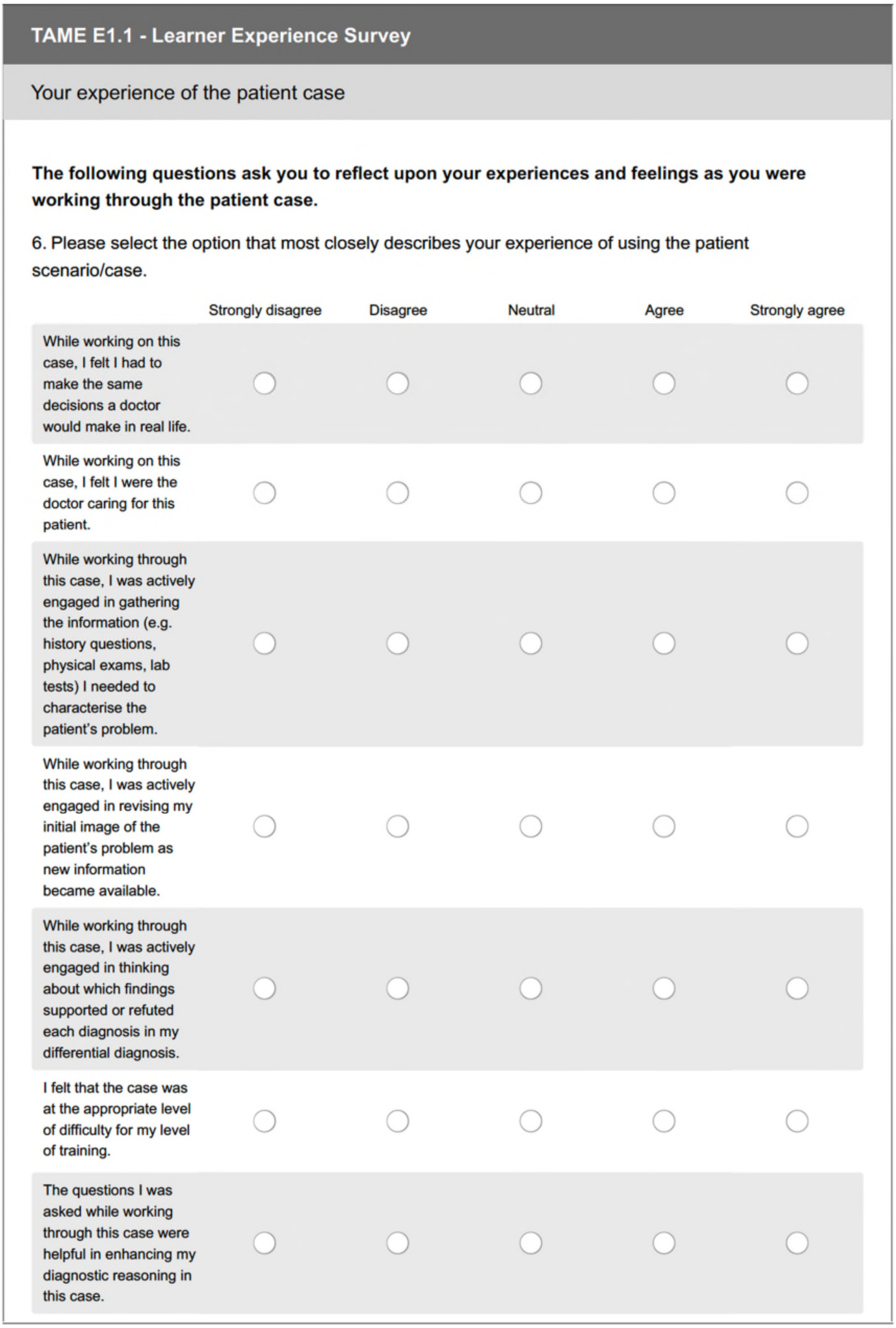
○ Dominic Barton

○ Jack Horner

○ Davina

○ Bella

○ Charlie



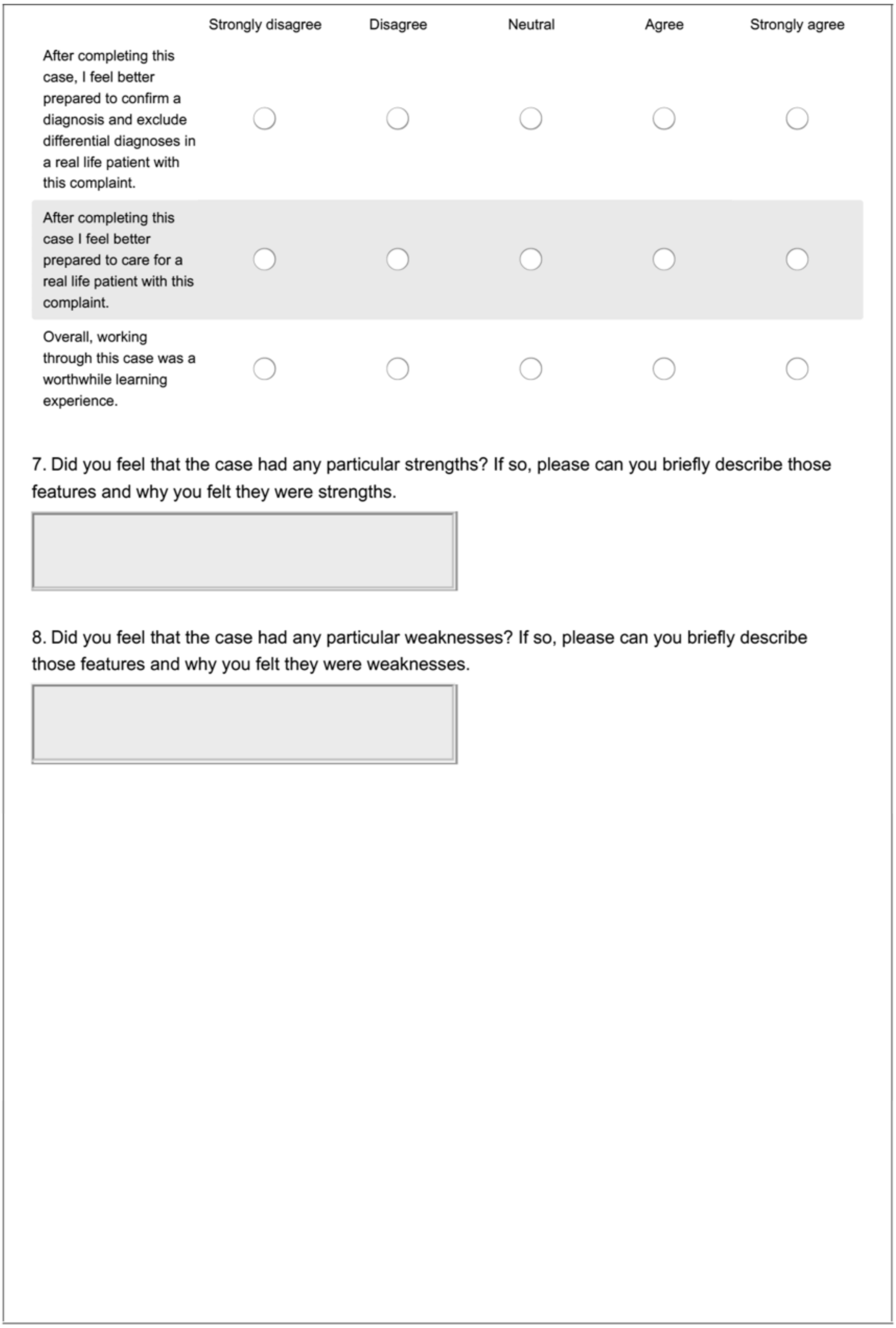
TAME E1.1 - Learner Experience Survey

Your experience of the patient case

The following questions ask you to reflect upon your experiences and feelings as you were working through the patient case.

6. Please select the option that most closely describes your experience of using the patient scenario/case.

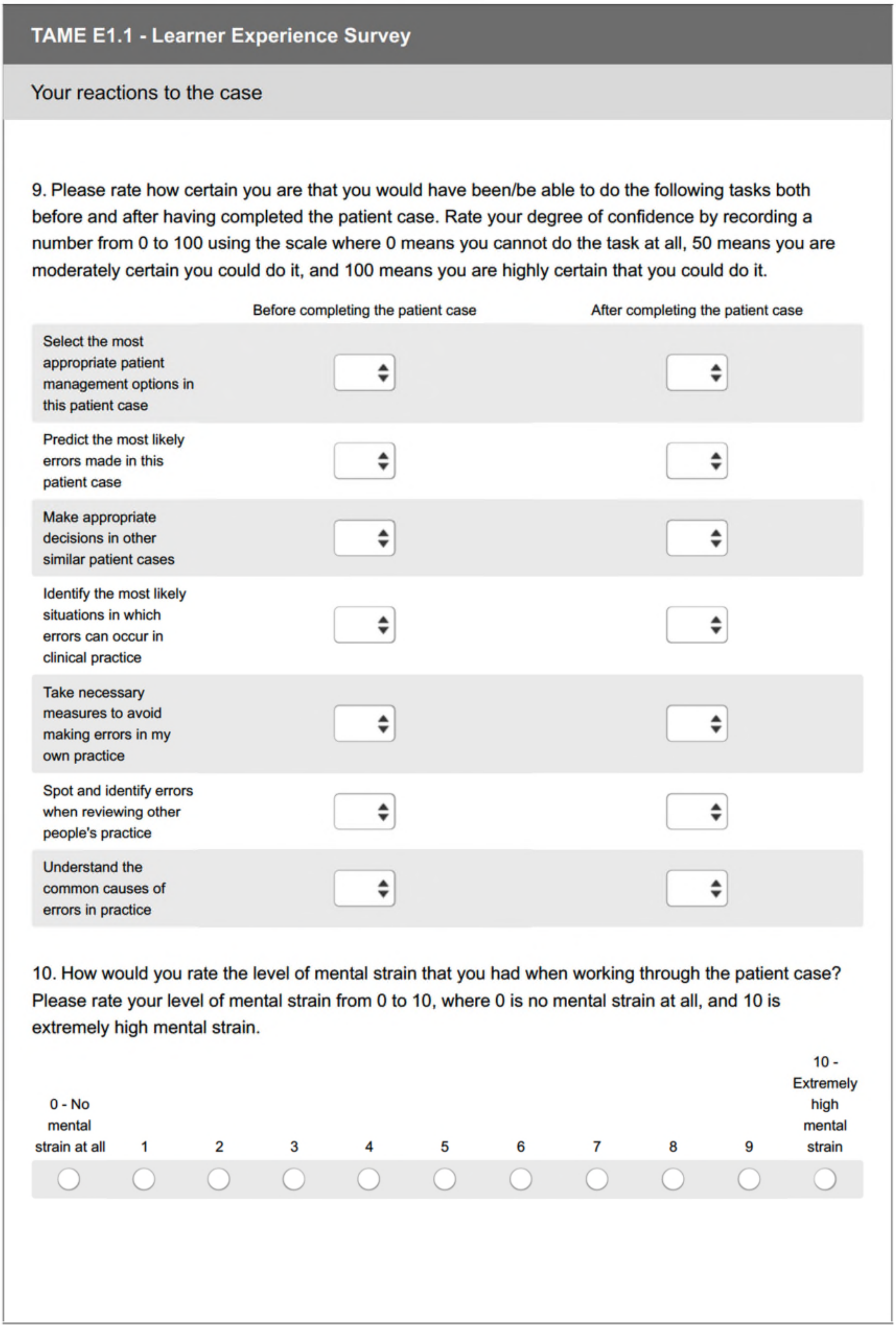
	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
While working on this case, I felt I had to make the same decisions a doctor would make in real life.	○	○	○	○	○
While working on this case, I felt I were the doctor caring for this patient.	○	○	○	○	○
While working through this case, I was actively engaged in gathering the information (e.g. history questions, physical exams, lab tests) I needed to characterise the patient's problem.	○	○	○	○	○
While working through this case, I was actively engaged in revising my initial image of the patient's problem as new information became available.	○	○	○	○	○
While working through this case, I was actively engaged in thinking about which findings supported or refuted each diagnosis in my differential diagnosis.	○	○	○	○	○
I felt that the case was at the appropriate level of difficulty for my level of training.	○	○	○	○	○
The questions I was asked while working through this case were helpful in enhancing my diagnostic reasoning in this case.	○	○	○	○	○



	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
After completing this case, I feel better prepared to confirm a diagnosis and exclude differential diagnoses in a real life patient with this complaint.	○	○	○	○	○
After completing this case I feel better prepared to care for a real life patient with this complaint.	○	○	○	○	○
Overall, working through this case was a worthwhile learning experience.	○	○	○	○	○

7. Did you feel that the case had any particular strengths? If so, please can you briefly describe those features and why you felt they were strengths.

8. Did you feel that the case had any particular weaknesses? If so, please can you briefly describe those features and why you felt they were weaknesses.



TAME E1.1 - Learner Experience Survey

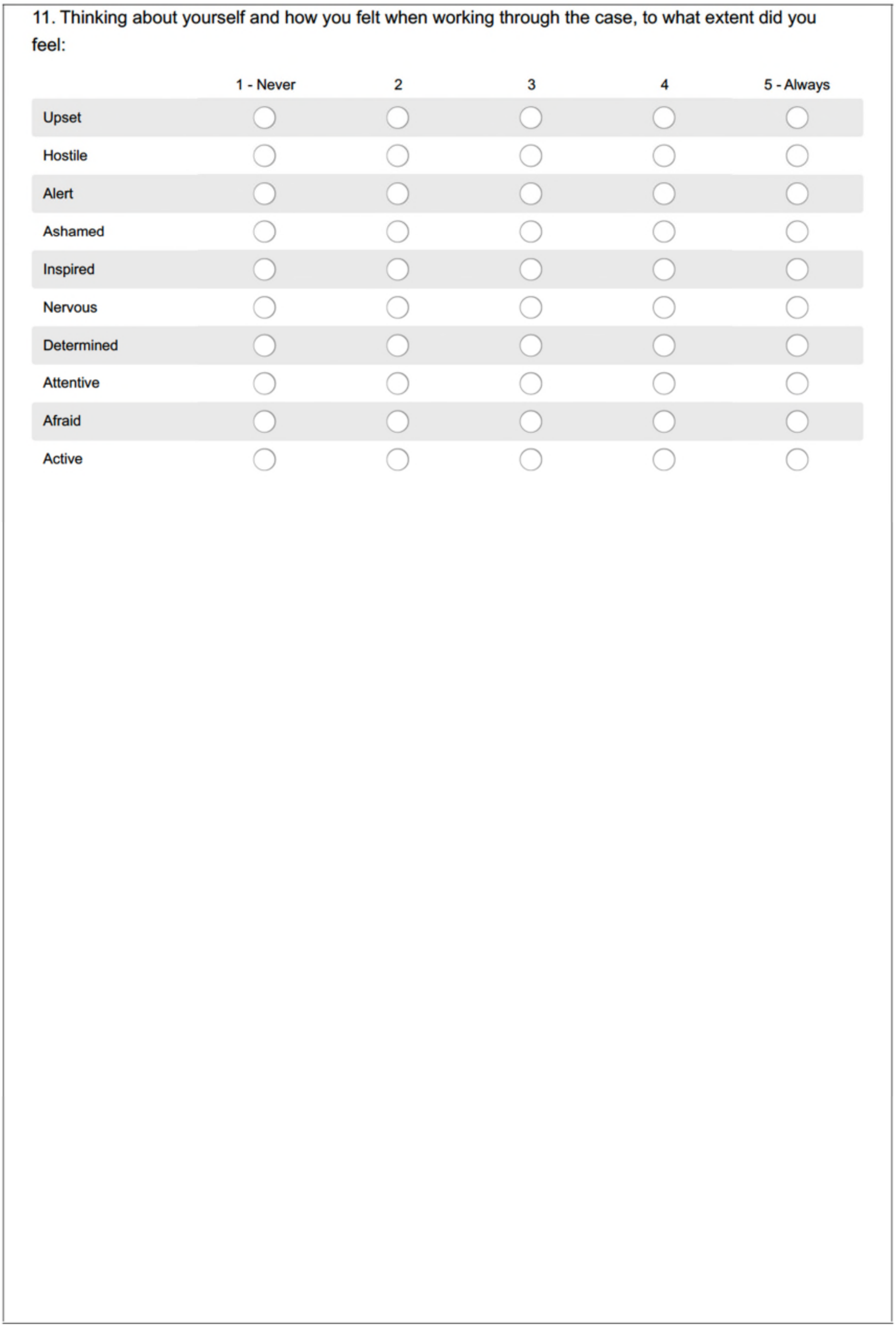
Your reactions to the case

9. Please rate how certain you are that you would have been/be able to do the following tasks both before and after having completed the patient case. Rate your degree of confidence by recording a number from 0 to 100 using the scale where 0 means you cannot do the task at all, 50 means you are moderately certain you could do it, and 100 means you are highly certain that you could do it.

	Before completing the patient case	After completing the patient case
Select the most appropriate patient management options in this patient case		
Predict the most likely errors made in this patient case		
Make appropriate decisions in other similar patient cases		
Identify the most likely situations in which errors can occur in clinical practice		
Take necessary measures to avoid making errors in my own practice		
Spot and identify errors when reviewing other people's practice		
Understand the common causes of errors in practice		

10. How would you rate the level of mental strain that you had when working through the patient case? Please rate your level of mental strain from 0 to 10, where 0 is no mental strain at all, and 10 is extremely high mental strain.

0 - No mental strain at all	1	2	3	4	5	6	7	8	9	10 - Extremely high mental strain
○	○	○	○	○	○	○	○	○	○	○



11. Thinking about yourself and how you felt when working through the case, to what extent did you feel:

	1 - Never	2	3	4	5 - Always
Upset	○	○	○	○	○
Hostile	○	○	○	○	○
Alert	○	○	○	○	○
Ashamed	○	○	○	○	○
Inspired	○	○	○	○	○
Nervous	○	○	○	○	○
Determined	○	○	○	○	○
Attentive	○	○	○	○	○
Afraid	○	○	○	○	○
Active	○	○	○	○	○

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