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Exploring the impact of education on preclinical medical students' tolerance of uncertainty: a qualitative longitudinal study

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Abstract
Tolerance of uncertainty, a construct describing individuals' responses to perceived uncertainty, has relevancy across healthcare systems, yet little work explores the impact of education on medical students' tolerance of uncertainty. While debate remains as to whether tolerance of uncertainty is changeable or static, the prevailing conceptual healthcare tolerance of uncertainty model (Hillen et al. in Soc Sci Med 180:62–75, 2017) suggests that individuals' tolerance of uncertainty is influenced by so-called *moderators*. Evidence regarding education's role as a moderator of tolerance of uncertainty is, however, lacking. Preliminary work exploring medical students' professional identity formation within anatomy learning identified tolerance of uncertainty as a theme warranting further exploration. Extending from this work, our research question was: *How does the anatomy education learning environment impact medical students' tolerance of uncertainty*? To address this question, qualitative data were collected longitudinally across two successive cohorts through online discussion forums during semester and end of semester interviews. Framework analysis identified five stimuli of uncertainty, four moderators of uncertainty, and cognitive, emotional and behavioral responses to uncertainty with variable valency (positive and/or negative). Longitudinal data analyses indicated changes in stimuli, moderators and responses to uncertainty over time, suggesting that tolerance of uncertainty is changeable rather than static. While our findings support the Hillen et al. (Soc Sci Med 180:62–75, 2017) model in parts, our data extend this model and the previous literature. Although further research is needed about students' development of tolerance of uncertainty in the clinical learning environment, we encourage medical educators to incorporate aspects of tolerance of uncertainty into curricular and learning environments.

Keywords Uncertainty · Ambiguity · Tolerance · Medical education · Qualitative longitudinal research · Anatomy

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Introduction

Tolerance of uncertainty is a construct describing how individuals respond to their perception of uncertainty (Hillen et al. 2017). Considered highly relevant to the functioning of healthcare professionals, low tolerance of uncertainty is thought to be associated with negative healthcare outcomes, such as burnout in both medical students and practicing doctors (Strout et al. 2018; Hancock and Mattick 2019). Despite a significant body of research exploring the impacts of clinician tolerance of uncertainty (Strout et al. 2018), debate in the literature still continues around the very nature of the construct: Is tolerance of uncertainty an individual characteristic (i.e. a static personality *trait*), or is it a complex construct (sometimes referred to as a *state*) resulting from, and modifiable by, the interplay between individuals and socio-cultural factors (Hillen et al. 2017)? Accordingly, whether education can impact medical students' tolerance of uncertainty, and potentially improve their preparedness for uncertainties in practice, remains unclear. To date, most studies on tolerance of uncertainty in medical education settings remain quantitative, cross-sectional studies; these studies focus on measuring students' tolerance of uncertainty and comparing this with their stage of education, albeit with inconsistent findings (Geller et al. 1990; DeForge and Sobal 1991; Merrill et al. 1994; Weissenstein et al. 2014; Hancock et al. 2015). This quantitative methodological approach is likely to contribute to current limitations regarding the tolerance of uncertainty construct definition cited, as these approaches tend to focus on outcomes and not exploration of construct underpinnings. Despite this poor understanding of the construct, some are using tolerance of uncertainty quantitative measures for assessment of medical education curricula and students (Association of American Medical Colleges 2019), thus tackling this research deficit is increasingly important and timely. To address this gap, we undertook an alternative research approach engaging a qualitative longitudinal study with preclinical medical students to better understand how education impacts students' tolerance of uncertainty.

Current theory on tolerance of uncertainty in healthcare

The most contemporary and comprehensive theoretical model for understanding tolerance of uncertainty in the context of healthcare is from Hillen et al. (2017). These authors undertook an interpretive conceptual analysis of tolerance of uncertainty, taking into account primary authors' conceptualizations of tolerance of uncertainty scales. Importantly, Hillen et al. (2017) acknowledge the considerable conceptual overlap between tolerance of uncertainty and related terms, especially tolerance of ambiguity (see Box 1 for a glossary of terms), with measures of both constructs included in the Hillen et al. (2017) review. The result was an updated definition for tolerance of uncertainty (Box 1), in association with their aforementioned model.

The Hillen et al. (2017) model describes tolerance of uncertainty through a stimulus-perception-appraisal/response framework. Stimuli include properties of information which may be perceived as uncertain, e.g. ambiguity (Box 1). Following this uncertainty perception, individuals' appraisals of, and responses to, uncertainty (i.e. their *tolerance*) fall into cognitive, emotional and behavioral domains. Within these domains, the responses can fall anywhere along a spectrum from negative (i.e. low tolerance or intolerance of uncertainty) to positive (i.e. high tolerance of uncertainty). Examples of negative appraisals and responses to uncertainty might involve the individual appraising uncertainty as threatening,

Box 1 Glossary of terms used in this paper

Term	Definition
Tolerance of uncertainty	"The set of negative and positive psychological responses—cognitive, emotional and behavioral—provoked by the conscious awareness of ignorance about particular aspects of the world" (Hillen et al. 2017)
Tolerance of ambiguity	"The tendency to perceive ambiguous situations as desirable" (Budner 1962)
Uncertainty	The "conscious awareness" (i.e. the perception) of "ignorance about particular aspects of the world" (Hillen et al. 2017)
Ambiguity	A source of uncertainty; a property of information pertaining to its lack of "reliability, credibility or adequacy" (Han et al. 2009; Hillen et al. 2017)
Grey cases	Clinical anatomy case-based learning with purposeful integration of ambiguity (see appendix for example case)

or denying its presence, feeling worried or fearful, and/or acting in maladaptive ways (i.e. avoidance, inaction or even circuitous action). By comparison, positive appraisals and responses might involve the individual having confidence and faith, feeling attraction or curiosity toward the uncertain scenario, and acting in adaptive ways, such as proceeding with judicious action and decision-making. Furthermore, the model allows for so-called *moderators* or factors which may modulate individuals' perceptions of uncertainty. Suggested moderators include characteristics of the stimulus, the individual and situation, as well as socio-cultural factors.

The inclusion of moderators within the model suggests that tolerance of uncertainty is a *modifiable* state, rather than a *fixed* personality trait. However, Hillen et al. (2017) contend that their model is designed to be flexible, and can be used by researchers from either a trait- or state-focused approach. Hillen et al. (2017) concluded that although their model was not intended to be a "grand unifying theory" for tolerance uncertainty, it could serve as an effective platform from which future research may be seeded. Taking the Hillen et al. (2017) model from a state-focused view, education could be considered a potential moderator of students' tolerance of uncertainty. However, this is presently an underexplored aspect of the tolerance of uncertainty construct.

Prior research on tolerance of uncertainty in medical education

Most existing studies assessing the impact of education on tolerance of uncertainty do so indirectly, by comparing participants' stage of training (e.g. first year compared with final year medical students, third year versus second year resident, etc.) with measured tolerance of uncertainty. Results of such studies are somewhat inconsistent, with some identifying an association between higher tolerance of uncertainty and more advanced stage of training (DeForge and Sobal 1991; Merrill et al. 1994; Hancock et al. 2015), and others unable to demonstrate any statistically significant associations between educational stage and tolerance of uncertainty levels (Geller et al. 1990; Weissenstein et al. 2014). A key limitation of these studies is that they are cross-sectional only, and as such, do not follow included cohorts longitudinally. Furthermore, by taking a quantitative approach to tolerance of uncertainty, insights into why or how education was (or was not) impacting these cohorts' tolerance of uncertainty remain elusive.

Conversely, an interpretivist approach to tolerance of uncertainty research, using qualitative research methodology, may be ideally suited to exploring the role of

education in moderating medical students' tolerance of uncertainty. Some qualitative research, albeit limited, explores medical student tolerance of uncertainty, and suggests that education can indeed have beneficial impacts. For example, Gowda et al. (2018) completed a mixed-methods study involving first-year medical students undertaking a museum-based visual arts elective, with one course objective focused on identifying and exploring uncertainty. They concluded that arts-based courses may facilitate medical student development of tolerance of uncertainty. Furthermore, Nevalainen et al. (2010) conducted a longitudinal qualitative study involving medical students in their first year of clinical placements and found that students' tolerance of uncertainty improved throughout the year via their written learning diaries. The authors concluded that reflective writing could facilitate medical students' expressions and processing of uncertainty.

Applying the Hillen et al. (2017) model to these two studies' interventions (visual arts and reflective writing) and their associated findings suggests a role for education in moderating students' tolerance of uncertainty. However, substantial gaps remain in our understanding of education's role in moderating tolerance of uncertainty. For example, both studies involved electives rather than core medical coursework (e.g. foundational biomedical sciences), so it remains unclear what impacts core science-based learning has on medical students' tolerance of uncertainty. Furthermore, findings from these studies are likely limited because of the absence of applied comprehensive theoretical models of tolerance of uncertainty, such as that of Hillen et al. (2017), through which to interpret their study findings.

One area of medical education that may be ripe for exploring medical student tolerance of uncertainty is anatomy education. While anatomy assessment (via examinations) often infers unambiguous correct and incorrect answers, thereby potentially impeding students' tolerance of uncertainty development, the anatomy discipline engages in much ongoing research into the unknowns of form, function, development and clinical applications. Furthermore, human anatomy is itself ambiguous in that it varies from person to person (known as *anatomical variation*). Such contradictions between disciplinary know-how (i.e. that anatomy is ambiguous) and anatomy education (e.g. that all anatomy is known and absolute) could serve to affect tolerance of uncertainty in unknown ways and with unknown (and possibly negative) professional impacts. For example, a lack of awareness of anatomical variation in clinicians is associated with negative outcomes, including medical errors and unnecessary procedures (Royer 2018). In this way, the anatomy learning environment provides a potentially rich environment for exploring the impacts of education on students' tolerance of uncertainty development.

Study aims and research question

This study aims to address a gap in the tolerance of uncertainty literature by identifying the impacts (either positive or negative) of education on preclinical medical students' tolerance of uncertainty in the context of a core medical curriculum (as exemplified by anatomy education), and to compare these aspects with the Hillen et al. (2017) model. Indeed, we explore the extent to which data from an anatomy education context aligns with and/or extends this prevailing tolerance of uncertainty theoretical model (Hillen et al. 2017). The research question for this study was: *How does the anatomy education learning environment impact medical students' tolerance of uncertainty*?

Methods

Following ethics approval (Monash University Human Research Ethics Committee Project Identification: 7167), we conducted a qualitative longitudinal research (QLR) study with undergraduate medical student participants at an Australian university. Data for this paper were collected as part of a larger research study exploring the impact of anatomy education on healthcare students' perceptions of their professional roles and identities, with data drawn from online discussion forums and semi-structured interviews. An overview of data collection in the larger study is previously described (Stephens et al. 2019). Preliminary data analysis of Cohort A, time point 1 data (see below) identified multiple professional identity and role themes relating to anatomy learning, including tolerance of uncertainty. This current paper serves to provide a deeper exploration of this theme in order to answer the posed research question.

Participants

We purposively sampled first year undergraduate medical students enrolled in the medicine program in 2016 (Cohort A, n = 301) and 2017 (Cohort B, n = 307). Online discussion forum invitations were sent via the course learning management system, with additional verbal invitations from teaching staff conveyed during anatomy classes. Interview participation was open to students who had participated in the online discussion forums during the preceding semester, with eligible students invited via e-mail.

Study context

In the current study, the first 2 years of medical education are largely preclinical. Students undertake anatomy during the second semester of first year, and both semesters of second year (see Fig. 1). The anatomy course involves traditional lectures, practical classes and team-based active learning. Practical classes are divided into four separate components involving: whole body human donor dissection; prosection classes (in which the focus is on student-led, but expert-facilitated identification of anatomical structures); medical imaging; and clinical anatomy tutorials. Students rotate through all components with equal time devoted to each.

During the anatomy course, students also participate in clinical anatomy case-based learning with purposeful integration of ambiguity, referred to as "grey cases" (Box 1). These cases involve a patient scenario with related clinical anatomy questions (example in supplementary material). Ambiguity was incorporated into these cases through case-related questions wherein multiple appropriate answers were possible based on the available information (e.g. differential diagnoses, selection of investigations, etc.). Grey cases are utilized in team-based active learning classes, online discussion forums and formative multiple-choice questions (MCQs) integrated within the prosection classes. Note that unlike traditional MCQs, grey case MCQs allow for multiple possible correct answers amongst the provided choices.

The grey case curricular components were introduced to students gradually. MCQs were implemented first, and were part of anatomy teaching prior to this research study. Following identification of tolerance of uncertainty as a theme within the larger research study (i.e. following analysis of Cohort A, time point 1 data; see Fig. 1), grey cases were introduced to team-based active learning classes and online discussion forums to further

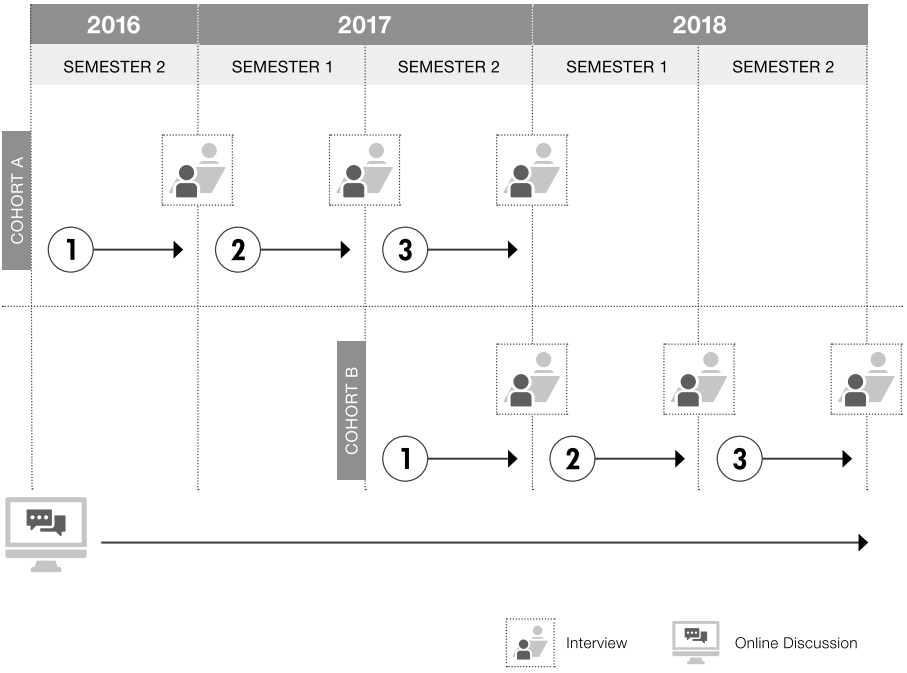

Fig. 1 Overview of study methods and time points

explore the impact of anatomy learning (including the grey cases) on medical students' tolerance of uncertainty. Summative assessments in anatomy do not incorporate tolerance of uncertainty concepts, in that a single best answer is expected.

Data collection

For both medical student cohorts, we collected data across all three semesters of student anatomy study in first and second year, as described previously (Stephens et al. 2019). Data were collected from online discussion forums conducted during semesters, and semi-structured interviews held at the conclusion of each semester (Fig. 1). Data were divided into three study time points corresponding to the three semesters of anatomy study (designated T1, T2 and T3; Fig. 1).

Online discussion forums

In total, 207 students across both cohorts participated in the online discussion forums, providing 54,228 words of data. Topics for discussion can be found in Table 1. As topics pertained broadly to student perceptions of professional roles and identities, student talk on tolerance of uncertainty was wholly unsolicited, i.e. students initiated discussions of uncertainty experiences in response to questions not explicitly querying this topic. The platform utilized for the online discussion forums was Verso© (Verso Learning, Melbourne, Australia). A key consideration in Verso platform selection was that students are only able to view and comment on peer responses once they

Table 1 Online discussion forum prompts by study time point

Time point	Online discussion forum (Verso©) prompts
1	How important is a base understanding of anatomy to your future role as a healthcare professional? Support your response with an example.
	To what extent would you be concerned if you found out that your healthcare professional caretaker had not learnt anatomy through donor dissection and why?
	After watching the video, to what extent do you think knowing your anatomy is necessary for healthcare practice? Is it okay to look up this information if you don't immediately know it?
	Finish this sentence: If I had access to staff and resources for an extra anatomy lesson this semester, I would most like to…
	1. What do you predict will be the emotions and thoughts you will experience on your first day in the anatomy laboratory? Include why you think this will be the case. 2. How do you think the class, as a whole, will act on this first day?
	After watching the linked video, how important do you think it is for this trainer to know his anatomy without looking it up? How would your answer differ if this was a hospital setting?
	Consider your learning relationships (e.g. peers, faculty, tutors) in your anatomy studies. Q1. Which relationships have had the most impact on your learning? Q2. Which relationships have the potential to be more impactful and in what ways?"[a]
	To what extent is your anatomy learning influencing your developing professional identity as a healthcare worker and why?[a]
2	If you were advising incoming students, what would be your top tip (or two) to help them prepare for and succeed in anatomy?
	Q1: What do you think the role of your anatomy educators/staff are in your learning? Q2: What is your role, as a student, in learning? Q3: How will your role, as it relates to learning, change as you become a medical professional?
3	A patient presents with ongoing pain and discomfort in their thigh with a history of chronic lower back pain. The patient has a two- month history of increasing aching and slight numbness in the affected thigh. They state "my leg just doesn't feel right". Your physical exam demonstrates loss of sensation on the patient's medial aspect of (R) thigh. Patient is unstable balancing on (R) lower limb compared to (L). Hip adductor strength (R) = 2/5 compared with (L) = 5/5 with manual testing. This clinician makes an initial diagnosis of referred symptoms from pathology related to L2 spinal nerve and develops a management plan based on that diagnosis. After months of failed improvement, the patient seeks a second opinion and undergoes additional testing. Following this second evaluation, the patient is diagnosed with a pelvic tumor impacting the (R) lateral pelvic wall (including the obturator nerve). Based on this scenario, was the first clinician competent or not? Why or Why not? After answering, find someone who disagrees with your opinion and discuss further.
	Reflecting upon your own experience, and since you are now nearing the end of your formal anatomy education… please share a profound or memorable learning experience you have had during your anatomy learning time. This can be positive or negative, but you are encouraged to choose something that really struck you or "sticks" with you even now.

Refer to Fig. 1 for an overview of study time points

[a]Topic not posted for Cohort B and instead discussed in semi-structured interviews

themselves post a response, thus helping to ensure that initial student responses are naïve and independent of peer opinions. Forums were moderated by the principal investigator (M.D.L), with discussion facilitated only by requesting students to: (a) elaborate on their answers; or (b) respond to peers' answers.

Semi-structured interviews

We conducted eleven semi-structured interviews to further explore themes identified in the online discussions. A total of 24 students participated in these interviews, with five of these students participating in two interviews at two different time points. Interview questions can be found in Table 2. Interviews were facilitated by C.E.R, G.C.S., S.R. and I.D. (see acknowledgements for latter two facilitators). In recognition of the potential for a power imbalance between the researcher and participants, the principal investigator (M.D.L.), who was also the anatomy discipline lead, did not facilitate interviews (Rees et al. 2019). While many questions and prompts were similar across the three study time points, questions were adjusted based on the online discussion forum data to ensure adequate theme exploration. Students discussed tolerance of uncertainty in a wholly unsolicited fashion in interviews conducted with Cohort A at all three time points, and with Cohort B for the first two time points. However, with Cohort B at T3, we solicited further explicit discussion about tolerance of uncertainty, with the following questions added to the facilitator script: "How have you managed ambiguity or uncertainty whilst learning anatomy, and has this changed over the course of your anatomy studies? If so, what has influenced this?" In interviews conducted with students from Cohort B at T3, participants, therefore, discussed the theme of tolerance of uncertainty in both an unsolicited *and* solicited fashion.

Although our initial study aim was broad, we considered that sufficient data collection for this QLR study across the two cohorts was achieved, because we: (a) had a sample with high specificity to our research question (i.e. preclinical medical students); (b) had high quality dialogue between the participants and researchers, particularly in interview data; (c) applied existing theory to our analysis of data; and (d) combined both cross-case and case analyses (Malterud et al. 2016).

Data analysis

We analyzed all data from the original study (Stephens et al. 2019) using framework analysis (Ritchie and Spencer 1994). Due to the longitudinal nature of this original study, we undertook an initial familiarization of the data from Cohort A at T1. At this stage, M.D.L., C.E.R. and S.P. (see acknowledgements) identified tolerance of uncertainty as a key theme for the original study on professional roles and identities. M.D.L. and G.C.S. then led the development of themes specific to tolerance of uncertainty (the focus of this paper). The Hillen et al. (2017) model of tolerance of uncertainty was identified as an appropriate theoretical lens through which to analyze these data as this model remains the most contemporary and comprehensive one specific to healthcare contexts, and thus medical students. Data analysis therefore took an abductive approach (Lingard 2015), whereby analysis oscillated between deductive (i.e. applying the Hillen et al. model (2017) to the data to aid in understanding student experiences of uncertainty) *and* inductive approaches (i.e. building theory on tolerance of uncertainty within the anatomy educational context). Through this approach, components of the Hillen et al. (2017) model were considered themes (i.e. Stimuli, Moderators and Appraisals/Responses), with subthemes detailing the specific Stimuli, Moderators and Appraisals/Responses identified within the anatomy education context. We used the qualitative data analysis software NVivo version 11.0 (QSR International, Melbourne, Australia) for data management and analysis.

Table 2 Semi-structured interview questions by cohort and study time point

Semi-Structured Interview Questions	Cohort A			Cohort B		
	T1	T2	T3	T1	T2	T3
What are the impacts (if any) of anatomy learning on your professional development?	✓	✓		✓	✓	✓
Can you discuss the impact of any learning relationships (e.g. peers, faculty, tutors) in your anatomy studies on your professional development?	✓	✓		✓	✓	
To what extent is Verso an effective tool for integrating professional identity curricula with anatomy teaching?	✓	✓		✓	✓	
To what extent do you think knowing your anatomy is necessary for healthcare practice? Is it okay to look up this information if you don't know it straight away?				✓		
Can you share with the group any profound or memorable learning experience you have had so far within anatomy learning? This can be positive or negative, but something that really stuck with you, or that might influence your perceptions of body donation?		✓			✓	
What impact, if any, do you think your anatomy education has on your ability to manage patient diagnosis, patient management, patient treatment, or proper patient care?					✓	
To what extent is your anatomy learning influencing your developing professional identity as a healthcare worker and why? Do any aspects of either the lecture or laboratory experience impact this?			✓		✓	✓
How have you managed ambiguity or uncertainty whilst learning anatomy, and has this changed over the course of your anatomy studies? If so, what has influenced this?						✓

Refer to Fig. 1 for an overview of study time points

Reflexivity

Once we established our research team, we participated in a team reflexivity exercise. This facilitated discussions of our understandings of, orientations to, and experiences of qualitative research within the study context (Barry et al. 1999). We found that we had diverse anatomy education experience (none, novice or expert), and qualitative research knowledge (novice or expert). We all had positive orientations towards qualitative methodologies/methods for answering the study research question. However, we possessed diverse attitudes (accepting to highly skeptical) toward the construct of tolerance of uncertainty. Skepticism of the construct was largely based around assumptions of tolerance of uncertainty as a stable and measurable personality trait, and its potential for overlaps with other constructs (Hillen et al. 2017). Despite this skepticism, however, all agreed that the Hillen et al. (2017) model of tolerance of uncertainty was the most applicable construct available for data interpretation and theory development.

Results

We found that the basic structure of the Hillen et al. (2017) model partly accounted for medical students' purported tolerance of uncertainty within the anatomy educational environment. Our results also illustrate that this model could be extended to accommodate novel findings in the context of medical education. Therefore, what follows is our presentation of: (1) the results related to the components of the Hillen et al. (2017) model, noting extensions to this model related to education; (2) longitudinal patterns in the data pertaining to tolerance of uncertainty as a dynamic state; and (3) an exemplar case to further illustrate the longitudinal patterns in student tolerance of uncertainty. Note that pseudonyms are used throughout to protect participant identities.

Themes relating to components of the theoretical model

We first present our themes and sub-themes relating to the Hillen et al. (2017) model (i.e. Stimuli, Moderators and Appraisals/Responses), indicating elements of our data supporting the model and components which serve to extend the model.

Stimuli of uncertainty

We identified five stimuli of uncertainty within our educational context, which we discuss in turn: (a) Studying anatomy; (b) Donor dissection; (c) Prosections; (d) Grey cases; and (e) The socio-cultural threshold of donor dissection.

Studying anatomy

Studying anatomy provoked student uncertainty, with students feeling unsure about which study approaches to use and how to manage content breadth:

> Just to know what we need to know because the topics are always so broad, you don't know where to focus on. (Susannah, Cohort A, T2, interview)

Donor dissection

Stimuli of uncertainty in donor dissection included the possibility of encountering anatomical variations, uncertainty in identifying structures in incomplete dissections (i.e. where only parts of a structure and its relationships were revealed) and the complexity of the dissection processes:

> … we were dissecting the cheek, and there's so much fascia… so much fat… so much other… connective tissue and it was very difficult to even find the artery, let alone look for its branches… it's not as clear as it seems. (David, Cohort A, T3, interview)

Prosections

While students also described anatomical variation as a stimulus of uncertainty in prosections, distinct differences were perceived between the two anatomy learning modalities. Students described prosections as clearer or even "*more accurate*" representations of anatomy, despite both being derived from, or utilizing, deceased human donors. Notwithstanding their purported clarity, prosections (often called "specimens" by students) appeared to stimulate uncertainty by enhancing student awareness of their anatomical knowledge limits, particularly around identifying displayed anatomical structures:

> … it's been difficult… dealing with ambiguity because sometimes it's really frustrating to walk into a specimens [class]… I was like, 'I have no idea what's going on'. (Jane, Cohort B, T3, interview)

Grey cases

Students described uncertainties in relation to the complexity of grey cases, the possibility for multiple correct or incorrect answers, and persistent uncertainties when model answers were not provided (as in the online discussion forums):

> In Verso… you don't know whether… your response is correct, or somebody else's [is]… so, maybe if after a few weeks… once they [students] do it [submit answer] they can see the model answer… that would just, sort of, give reassurance, I think? Otherwise you could just believe that you're right or you can believe that they're [other students] right, and you're wrong… (Anushka, Cohort B, T2, interview)

The socio-cultural threshold of dissection

Anticipating commencing donor dissection classes stimulated uncertainty for some students, a concept we termed the *socio-cultural threshold of dissection* (which is about students' reported uncertainties in crossing a perceived threshold by participating in a social act—dissection of whole-body human donors—that is normalized in medical education but otherwise culturally taboo). This stimulus was thus largely discussed by students at T1, when the threshold was anticipated, and consequently crossed:

> Emotionally, I feel somewhat nervous… because I have never seen a cadaver before, and as such, am unsure how I will react to it. Most people never even consider looking at a cadaver in real life, so there's no learned 'appropriate social behaviour', except to show respect… (Angelique, Cohort B, T1, Verso)

Moderators

Within anatomy education, students' tolerance of uncertainty appeared to be either facilitated or impeded by perceptions related to: (a) peers; (b) experts; (c) society and patients; and (d) grey case contexts.

Peers

The impact of peers on student tolerance of uncertainty seemed to differ depending on whether students felt individually or collectively responsible for knowledge (as in shared responsibility with their peer team). Students' talk suggested that they were less tolerant of uncertainty when they thought they were solely accountable for an answer. Contrastingly, working within a team seemed to positively impact student tolerance of uncertainty:

> So, you've got, like, four or five other people standing around you, so you can be, like, 'do you know what that is, could you explain why this is like that'. (Alexandra, Cohort A, T3, interview)

This positive impact was chiefly described in the context of donor dissection, where students were divided into small groups of approximately five students per donor. Interestingly, in relation to grey cases implemented in the online discussion forums, students suggested that being anonymous to peers also improved their tolerance of uncertainty.

Experts

Student talk on anatomy teaching staff suggests that they could either facilitate or impede students' development of tolerance of uncertainty depending on their approaches when responding to students' expressions of uncertainty. Experts simply providing answers seemed to impede students' tolerance of uncertainty, either by distracting students from uncertainties present through didactic approaches, or by failing to acknowledge ambiguity/uncertainty when it was actually present. Conversely, student talk about experts guiding them toward multiple possible answers by providing relevant evidence and reasoning behind the validity of several answers, and/or experts' acknowledgement of uncertainty when present, were both suggested to facilitate students' tolerance of uncertainty. These moderators of students' tolerance of uncertainty could be actioned by educators through behaviors as simple as informing students that they did not know an answer, and communicating *why* the answer may be difficult to ascertain, enabling students to develop an awareness of the relevant ambiguities:

> If we ask a tutor that question, sometimes the tutors will say that they themselves don't know, and that's as far as they can get as well, just by observing the body… (Rebecca, Cohort B, T2, interview)

Society and patients

Some students predicted the impact of uncertainty on their future patient encounters. Herein students reported that doctors were expected to know all the answers to patient questions, and that *not* knowing could negatively affect the doctor-patient relationship. These beliefs therefore appeared to negatively impact students' tolerance of uncertainty:

> I know if I was a patient and had no idea what was happening I would be extremely upset and worried if I felt my doctor did not understand what was happening. (Melissa, Cohort B, T1, Verso)

Grey case context

Patient acuity and setting appeared to moderate student tolerance of uncertainty in the context of grey cases. For example, descriptions of emergency settings appeared to negatively impact students' tolerance of uncertainty, as did the theoretical availability of diagnostic resources such as imaging. Indeed, students described using available diagnostic resources as a means of attaining greater certainty in the grey cases:

> … they [hospital doctors] often have the luxury of being able to run tests and/or take imaging of the site of injury. This can provide them with a more thorough understanding of what is occurring, giving them further insight with how best to proceed. (Zoe, Cohort B, T1, Verso)

Appraisal/response

Student reports of their responses to uncertainty aligned with all three domains (cognitive, emotional and behavioral) described in the Hillen et al. (2017) model. While student responses were often limited to describing a single domain, some responses (especially those obtained through interviews) described responses across multiple domains.

Cognitive appraisals

Students' cognitive appraisals varied from negative to moderately positive.

Negative appraisals Negative appraisals included students communicating a desire for defined answers, doubting their levels of knowledge, conveying a need for expert validation of answers, and expressions of absolutism in relation to anatomy and/or medical knowledge:

> I believe it is very important that a doctor knows where everything is in the human body and can identify what is normal. (Nalini, Cohort A, T1, Verso)

Moderately positive appraisals Moderately positive appraisals included an acceptance of tolerance of uncertainty as a clinical competency, whereby students acknowledged that it would be required for their future practice:

> Also, medicine… is so ambiguous… So, I think it's good to be exposed to things we don't know because genuinely some things we just don't know, and even the most

> learned people don't know, and so I think we need to be comfortable… [that] this happens and we don't know why and no one knows why… (Jane, Cohort B, T3, interview)

Emotional responses

Emotional responses to uncertainty were almost exclusively negative in our data. Students described feeling "*nervous*", "*frustrated*", "*guilty*" or "*overwhelmed*" in the face of uncertainty. Perhaps most significantly, students expressed a "*fear*" of errors related to both the anatomy course and future patient care:

> If I'm a doctor and I get the wrong diagnosis, and that has a bad impact, I'm a bit nervous about that. (Lucy, Cohort B, T3, interview)

Behavioral responses

The described behavioral responses to uncertainty included a full spectrum of actions from negative/maladaptive to positive/adaptive.

Negative behaviors Negative behaviors included students describing avoidance and inaction as responses to uncertain stimuli:

> There is no access to any answers anywhere for us which is… a really big pain, because I found for this semester I didn't answer any questions in my book. (Nalini, Cohort A, T2, interview)

In relation to grey cases, students remarked that they sought certainty prior to decision-making (e.g. using further resources such as medical imaging).

Positive behaviors Positive behavioral responses included student descriptions of perseverance and decision-making in the face of uncertainty. For example, students described committing to an answer in grey cases even with limited information, or persevering in attempting to identify anatomical structures despite an initial reflection on the limitations of their anatomical knowledge:

> But I think it's really important to just press on and try and find out where things are… it's good character building in a way just to like be like 'I don't know what's going on but I'm going to try find out'… (Jane, Cohort B, T3, interview)

Furthermore, some students described disclosing uncertainty as a positive behavioral response, specifically in being honest in acknowledging unknowns to patients as important to the doctor-patient relationship *and* patient safety:

> Looking up anatomy information if you don't know… it's a responsibility under the doctor's duty of care to the patient. A doctor should have the humility to admit when their knowledge isn't up to scratch and they need to do more research, lest they make medical decisions with flawed information and potentially cause harm to the patient. (Jonathan, Cohort B, T1, Verso)

Behavioral responses with variable valency Two additional behaviors described by students could be positive, negative or indeterminate depending on context: information-

seeking and deferral to experts. While information-seeking was largely described by students as positive in relation to uncertainty (e.g. studying prior to dissection in response to previous uncertainty), some students described seeking information without progression towards decision-making, suggesting that this behavior could also be negative. Such negative responses were seen particularly in talk about grey cases, in which some students described researching answers for lengthy periods of time without arriving at decisions:

> So, the questions in the book we do for anatomy… you can search for hours and unless someone really tells you who knows, you can just get a good guess. (Nalini, Cohort a, T2, interview)

Deferring to experts in the face of uncertainty was also described in response to grey cases and predicted future practice:

> … it is impossible to know everything in medicine - it is a collaborative practice in which we work in teams and we do refer people to specialists. In that sense it is appropriate and advisable to refer it onto someone else who knows the anatomy of say a foot injury… (Deborah, Cohort B, T1, Verso)

However, students generally failed to detail whether this deferral to experts had features associated with negative (e.g. *avoiding* the patient and referring them on to another practitioner) or positive responses (e.g. *information-seeking* through history and examination, then *decision-making* regarding appropriate specialist referral).

Temporal changes

When data were analyzed longitudinally, we identified several temporal patterns across the entire dataset.

Changes in stimuli

At T1, the stimulus for uncertainty dominant in student talk was the socio-cultural threshold of dissection, identified most clearly in response to the online discussion forum question: "*What do you predict will be the emotions and thoughts you will experience on your first day in the anatomy laboratory?*" This question was posed in the first week of semester, prior to students' engagement in dissection. The stimulus for uncertainty apparent as most dominant within student talk during interview data at T1 (i.e. after students' first semester of anatomy study), was studying anatomy. By T2, the dominant uncertainty stimulus transitioned to grey cases, coinciding with the introduction of team-based active learning developed around these cases. The amount of talk relating to donor dissection as a stimulus for uncertainty also seemed to increase across all three time points, resulting in this theme being the foremost uncertainty stimulus at T3.

Changes in moderators

Experts were consistently reported as a moderator of student tolerance of uncertainty across all three time points. However, peers were identified as the dominant moderator

of uncertainty tolerance at T2, coinciding with the introduction of team-based active learning.

Changes in appraisals and responses

Uncertainty appraisals/responses varied in students' talk across the three time points most clearly in relation to the cognitive domain (Fig. 2). The dominant cognitive appraisal at T1 was a belief in absolutes in anatomy and/or medicine (i.e. suggesting a negative appraisal). At T2, the dominant appraisal was a need for expert validation of answers and doubt in students' knowledge (still suggestive of a negative appraisal, but perhaps now associated with an awareness of ambiguity). By T3 however, the dominant appraisal described by students was accepting tolerance of uncertainty as a clinical competency. While not an overtly positive response, this does suggest a pattern from negative (in the two earlier time points) to moderately positive appraisals by T3 (Fig. 2). As previously described, while emotional responses were substantively negative across the entirety of the study, fear of errors was particularly dominant in students' talk at T2, again coinciding with the introduction of team-based active learning grey cases. Behavioral responses expressed in students' talk were fairly consistent across the study (with information-seeking being the dominant response at all times points).

Illustrative longitudinal case

An example longitudinal student case further illustrates the temporal thematic changes identified in the larger study (Box 2). Brian (pseudonym) was chosen as an illustrative case because he participated in the study across all three time points, and described experiences with uncertainty reflecting the wider longitudinal patterns identified within the cohort.

Brian participated in online discussion forums across the study and in interviews at T2 and T3. At T1 he described concepts of absolutism in medicine (i.e. a negative cognitive appraisal), specifically that a doctor seeking information was suboptimal (Box 2, quotation

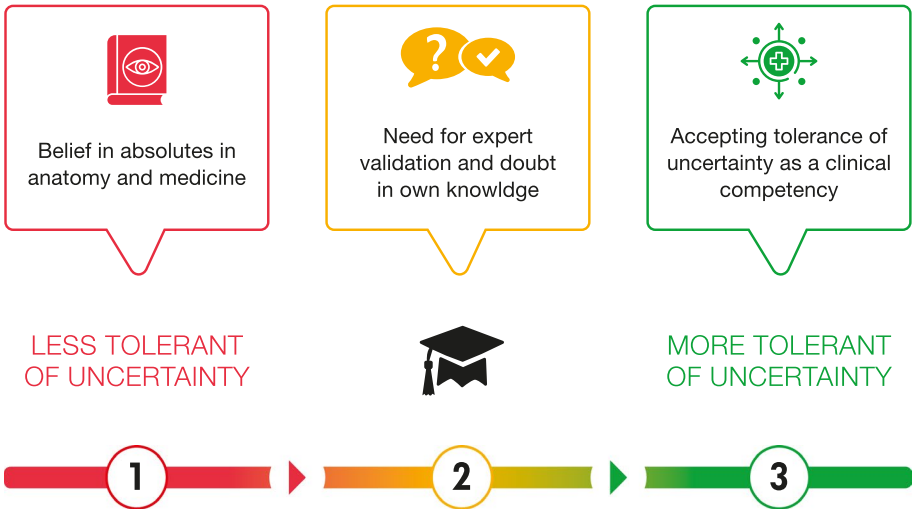

Fig. 2 Patterns in students' cognitive appraisals of ambiguity by study time point

Box 2 Illustrative longitudinal case

Time point	Quotations
1	i. Having a doctor look up information that they should… already know is subpar… the doctor's job is to gather all the necessary information then treat the patient correctly. However, it is better than the doctor treating the patient with incomplete knowledge.
2	ii. … originally you just thought the body was like, everything was where it's meant to be, and then you learn something about accessory spleens, the palmaris longus, about like, veins that are just, like, all over the place. iii. … with diagnosing patients, I guess you've got a differential diagnosis, and without enough information, I guess there could be multiple correct answers… maybe things like anatomy, there's always one correct answer to a multiple-choice question… Versus in real life, there could be multiple correct answers… you just have to accept that and work with that, until you can get down to one answer, or more correct answer.
3	iv. … initially when I thought of anatomy, I thought 'oh, this thing would always be in this part of the body', but then we learn later on that there are so many variations… you've got to be prepared for it [variations], otherwise you'll be like, 'oh, I know there's nothing important here'… I think the example was an aberrant obturator artery. They [the patient] might have something there and if you're not prepared for it to be ambiguous, if you're not cautious, then you could make a mistake, and then that could cause problems.

i). Interestingly, Brian uses the phrase "*incomplete knowledge*", suggesting a belief that knowledge can be complete. At T2, however, Brian describes a developing awareness of ambiguity in his interview by recounting learning about anatomical variation through donor dissection (Box 2, quotation ii). He also appears to now accept ambiguity as a feature of knowledge, but states that whilst this is the reality of clinical practice, this is not actually the case within the context of anatomy exams (Box 2, quotation iii). At T3 in his second interview, Brian further describes experiencing uncertainty through anatomical variation, and how ignorance of ambiguity could result in clinical practice errors (Box 2, quotation iv). Thus, Brian appears to shift from a negative cognitive appraisal of uncertainty at T1, through to acknowledging the presence of ambiguity and its relevance to clinical practice at latter time points.

Discussion

Summary of key findings in comparison to existing theory

This is the first study exploring medical students' experiences of tolerance of uncertainty in the context of anatomy education, including both cross-sectional and longitudinal qualitative data. Importantly, this study suggests that tolerance of uncertainty is changeable rather than a static personality trait (Hillen et al. 2017). Our findings also illustrate how anatomy education may impact medical students' tolerance of uncertainty development, and how educational contexts more generally may impact students' tolerance of uncertainty.

Our findings demonstrate that the basic elements of the Hillen et al. (2017) model of tolerance of uncertainty (i.e. Stimuli, Moderators and Appraisals/Responses) may be extended to the context of anatomy education. Specifically, students describe experiencing uncertainty related to the stimuli of learning anatomy in general, as well as to the specific educational approaches used (donor dissection, prosections and grey cases). Moderators of

tolerance of uncertainty described within anatomy education were primarily people (i.e. anatomy educators, peers, and perceived patient expectations), but also the context provided within the theoretical clinical settings of grey cases.

Student responses to uncertainty were described in cognitive, emotional and behavioral domains. Hillen et al. (2017) designated a spectrum of possible responses from negative to positive, with categorical suggestions of how these responses may manifest (e.g. negative cognitive response manifesting as doubt). However, both the response *range* and *manifestations* discussed by our student participants appeared somewhat divergent from those suggested by Hillen et al. (2017). For example, cognitive responses described by our participants ranged from negative (e.g. *doubt*) to moderately positive (e.g. *acceptance*). The manifestations of fully positive appraisals proposed by Hillen et al. (2017) (e.g. opportunity, confidence and faith) were not identified in our data. The longitudinal pattern toward acceptance found in our data does, however, suggest that positive responses to uncertainty could still develop in students as they progress through medical school. Furthermore, while Hillen et al. (2017) proposed positive emotional responses (e.g. calm, curiosity and hope), emotional responses to uncertainty described by our students were exclusively negative and steadily so. Finally, behavioral responses described by our students ranged from negative/maladaptive to positive/adaptive, consistent with Hillen et al. (2017).

Our qualitative findings also extend the Hillen et al. (2017) model. For example, when students described responses across multiple domains (cognitive, emotional and/or behavioral), where these responses fell along the negative–positive spectrum could vary markedly between these domains. For example, despite describing a negative response to uncertainty in the emotional domain (e.g. fear), a student could simultaneously describe a positive response in the behavioral domain (e.g. information-seeking). The reason for this disparity (or what was *moderating* these responses) was not always clear in our data; this appraisal/response incongruency raises questions about the validity of existing quantitative tolerance of uncertainty studies, where participants are stratified simply into high or low tolerance of uncertainty holistically. Instead, our results suggest that individuals may appraise and respond to ambiguous educational stimulus both positively *and* negatively, depending on the appraisal/response domain discussed. This suggests that tolerance of uncertainty is a more complex and socially determined construct than is implied by the current Hillen et al. (2017) model. Indeed, we would argue that overall stratification into levels of tolerance (high or low) are too simplistic.

A further extension of the Hillen et al. (2017) model based on our findings is that a behavioral response could either be adaptive or maladaptive depending on context. Hillen et al. (2017) describe categorical responses along this spectrum (e.g. avoidance is categorized as a negative behavioral response, whereas action is categorized as a positive behavioral response). However, our data suggests that the behavioral response of information-seeking has variable degrees of adaptability. For example, some students described information-seeking as an adaptive response enabling them to proceed with action and decision-making, consistent with Hillen et al. (2017). Conversely, other students described information-seeking not resulting in subsequent action (i.e. *inaction*), a maladaptive response). Hillen et al. (2017) suggest that behavioral responses may be further classified temporally as source-focused (aiming to circumvent or change the uncertain situation) or consequence-focused (aiming to alleviate the ramifications of an uncertain situation). *Inaction* by students in our study could be considered a source-focused behavior, as they simply avoided the source of uncertainty. Yet *information-seeking* could also be considered source-focused, as students sought to change the level of uncertainty by gathering information. Data from our study suggests a temporal relationship exists between these two

source-focused behaviors, whereby information-seeking was followed by subsequent action or inaction, suggesting a further level of nuance to behavioral responses not captured previously by the Hillen et al. (2017) model.

Comparison of findings with existing literature

Dominance of negative emotional responses

While the lack of positive emotional responses to uncertainty found in our data was a notable divergence from the Hillen et al. (2017) model, existing literature on tolerance of uncertainty in medical students and doctors appears to mirror these findings. Fear of errors in relation to exams and future practice were described by students in our study as negative emotional responses to uncertainty, with this being more dominant at T2 (coinciding with the introduction of grey cases in team-based active learning) than T3. Similarly, Nevalainen et al. (2012) identified that low tolerance of uncertainty was linked to fear of errors in medical students prior to their general practice placements. However, this survey-based study was conducted at a single time point only. Our findings regarding changes in fear of errors over time add to this previous literature by suggesting that tolerance of uncertainty is a dynamic and modifiable state, and pedagogies such as grey cases might allow students to gain much-needed experience with uncertainty and develop a means for processing their fears.

Although our study did not explicitly explore burnout or reduced psychological wellbeing as negative emotional responses to uncertainty, much of the existing literature into the impacts of lower tolerance of uncertainty focuses on these areas (e.g. Lally and Cantillon 2014; Takayesu et al. 2014; Hancock and Mattick 2019). Indeed, a recent systematic review into tolerance of uncertainty and psychological wellbeing in medical students included eleven studies, all of which reported associations between lower tolerance of uncertainty and reduced psychological wellbeing (Hancock and Mattick 2019). Our findings in association with this broader literature suggest that medical students' negative emotional responses to uncertainty may subsequently lead to more serious consequences, such as burnout and mental health problems, as they progress to later-stage students and practicing doctors (Hancock and Mattick 2019). Given that most of the existing studies employed quantitative approaches to measuring burnout, further longitudinal qualitative research may improve our understanding of how negative emotional responses to uncertainty in medical students might subsequently lead to psychological illness and burnout.

Behavioral responses with parallels to clinical practice

In response to uncertainty fueled by grey cases, our students described seeking certainty, largely through the accumulation of additional data (e.g. theoretical requests of further investigations), before committing to answers. Similar findings are reported in practicing clinicians, where poor tolerance of uncertainty is linked to over-ordering of inappropriate investigations (Allman et al. 1985; van der Weijden et al. 2002; Lysdahl and Hofmann 2009). Our students also described deferring to experts in response to uncertainty, although the appropriateness of this behavior was not often articulated. Similarly, in clinical settings, low tolerance of uncertainty is associated with increased referrals from primary care physicians and a reluctance to disclose uncertainty to their patients and other physicians (Forrest et al. 2006). Although preclinical medical students are not yet responsible for ordering

investigations or writing specialist referrals, they will be observing these behaviors once they begin clinical placements. Intervention at the preclinical stage through purposeful and planned exposure to decision-making in the face of uncertainty (e.g. grey cases) may begin to facilitate students' awareness of uncertainty in healthcare, and their own tolerance of uncertainty, before they start to experience and/or observe negative responses to uncertainty in clinical settings.

In summary, our findings are largely consistent with previous literature about the emotional and behavioral responses to uncertainty. However, our longitudinal data provide a deeper understanding of how education can impact such responses, and offer novel findings by suggesting that student cognitive appraisals of uncertainty improved over time and with exposure to uncertainty stimuli in the context of anatomy education.

Methodological strengths and challenges of the study

A major strength of our study is the QLR methodological approach, incorporating data collection from two cohorts of medical students over three years. A depth of data was obtained through students' participation in online forums and interviews across all time points. We also conducted a rigorous, team-based data analysis that drew on, and ultimately extended, an existing theoretical model (Hillen et al. 2017). Our findings are partly supportive of the Hillen et al. (2017) model, suggesting some conceptual generalizability to other higher education settings (Firestone 1993). For example, the noteworthy role of the educator in moderating students' tolerance of uncertainty and the use of questions without definitive answers as uncertainty stimuli may be applicable across higher education.

Our study, however, had some challenges. It was limited by its reliance on student recollections and descriptions of their experiences rather than direct observation of students' behavioral responses. Furthermore, student participation in the online discussion forums declined over time, meaning that our conclusions from latter time-points may be more tentative. In most stages of data collection, student discussion of tolerance of uncertainty was unsolicited rather than solicited. Indeed, collection of more solicited data from students about tolerance of uncertainty, might have identified additional evidence for elements of the Hillen et al. (2017) model not currently supported by our data (e.g. positive emotional responses), or further themes relating to components of the model (e.g. the role of knowledge acquisition as a moderator, etc.). Furthermore, this study was completed at a single Australian medical school with undergraduate students, and as such our findings may lack transferability beyond this context (e.g. graduate entry students). Finally, while our data suggests that anatomy education can foster student tolerance of uncertainty, we did not evaluate whether experiencing uncertainty in preclinical anatomy education impacts students' tolerance of uncertainty in other (e.g. clinical) contexts.

Educational implications

Our findings suggest that education may be a formidable moderator of tolerance of uncertainty, with multiple aspects of the learning environment impacting student tolerance of uncertainty (Fig. 3). Therefore, educators should feel confident in trying to incorporate tolerance of uncertainty paradigms into existing curricula, even traditionally content-heavy science courses. Although some stimuli of uncertainty identified were specific to anatomy education (i.e. donor dissection and prosections), some may have relevance to other tertiary education or professional school contexts (e.g. breadth of study content, use of questions

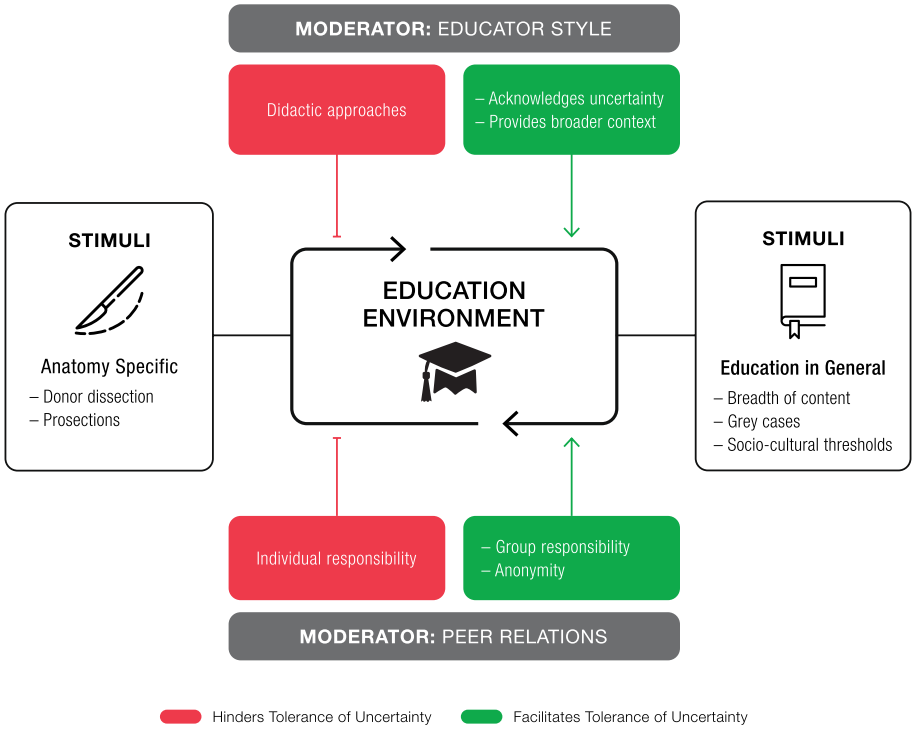

Fig. 3 Aspects of the learning environment which impact student tolerance of uncertainty

without definitive answers, etc.). Practical approaches for educators to foster students' tolerance of uncertainty suggested by this research include: (1) Acknowledging where ambiguity is present; (2) Admitting when an answer to a student's question is unknown, and using evidence to explain why the answer is difficult or unable to be obtained; and (3) Guiding students toward likely answers with a discussion of relevant context. Given the positive impact that teamwork appeared to have on tolerance of uncertainty, educators might also consider how teamwork could be encouraged amongst students in ambiguous settings (e.g. team-based active learning with ambiguous questions). Furthermore, introducing students to ambiguity in settings with a higher emphasis on individual responsibility for answers (e.g. online discussion forums requiring an initial response naïve to peers) may also prepare students for future settings in which greater autonomy of practice is required.

Clinical anatomy grey cases may be an ideal way of facilitating student tolerance of uncertainty in a context linking anatomy content to future clinical practice. While this approach may be associated with an initial negative emotional response in students, we would encourage a step-wise approach to introducing students to uncertainty, with consideration of key moderators at each stage. For example, uncertainty may be best introduced in a team-based learning environment, where either anonymity is maintained (as in online discussion forums) or where responsibility for knowledge is dispersed amongst the team (as in donor dissection and team-based active learning), before transitioning to settings where students have individual responsibility for answers (e.g. call-out in class or

individual responses required online). Finally, although grey cases were used in this study for clinical anatomy learning, there is scope for grey cases to be adapted to other disciplines. Importantly, these cases appear to allow for a fine balance between discipline-based content-knowledge and developing tolerance of uncertainty, both of which are needed for effective healthcare practice.

Future research

Hillen et al. (2017) describe their model as foundational to further theoretical research into tolerance of uncertainty. Indeed, our findings suggest that each component of the Hillen et al. (2017) model may have levels of complexity still remaining to be elucidated, particularly within the educational realm. Therefore, further research to develop our theoretical understandings of tolerance of uncertainty in medical students is warranted, and might involve purposefully exploring tolerance of uncertainty in the clinical learning environment. We would argue that future research efforts may benefit from qualitative approaches based on social constructionist epistemologies because these approaches could help to explore the nuanced complexities of tolerance of uncertainty and its components (i.e. the interplay between stimuli, moderators and appraisals/responses). A key research priority should be further exploring how tolerance of uncertainty impacts emotions, and whether interventions can be formulated to help prevent burnout related to low tolerance of uncertainty.

Conclusions

This study, for the first time, illustrates medical students' experiences of uncertainty within the context of anatomy education. We identified a range of educational stimuli (some specific to anatomy, others potentially applicable across the educational sector) in which students perceived uncertainty, noting in particular that educators facilitated or hindered students' tolerance of uncertainty development depending on their pedagogical approach. Importantly, this study suggests that preclinical medical school curricula may be structured to balance discipline-based content knowledge with student development of tolerance of uncertainty.

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Appendix

Grey case example: 23-year-old male with shortness of breath

Initial information: A previously fit and well 23-year-old male has been admitted to the trauma ward following a high-speed motor bike accident three days ago. He sustained the following injuries:

- Left mid-shaft femur fracture
- Left 6–8th rib fractures
- Multiple minor abrasions

His femoral fracture underwent surgical fixation with an intramedullary nail and he is currently non-weight bearing on that limb. He presses the call bell at his bedside because he begins experiencing shortness of breath.

Question 1: You are the surgical resident called to review the patient. What additional information would you prioritise and why?

A. CT chest
B. MR thorax
C. Vital signs
D. Chest XR
E. Respiratory examination
F. Medication review
G. Take a relevant history
H. Review surgical site
I. Arterial blood gas
J. ECG

Further information following question 1:

- History—sudden onset dyspnoea half an hour ago, some pain on inspiration
- Medication review—analgesia and antibiotics only
- Vital signs—SaO2 92% on 4L oxygen, HR 125 beat/min, BP 130/70, afebrile.
- Examination—auscultation of lung fields normal
- Chest XR—normal

Question 2: What is your differential diagnosis? Justify all answers using relevant anatomy and research.

A. Acute myocardial infarction
B. Pneumonia
C. Pneumothorax
D. Fat embolism syndrome
E. Pulmonary embolism
F. Bronchospasm
G. Hypoventilation secondary to opioids
H. Pain from rib fractures

Further information following question 2: The patient is given low molecular weight heparin (anticoagulant) for treatment of suspected pulmonary embolism which is then confirmed on CT pulmonary angiogram (CTPA).

Question 3: Where did the embolus originate?

A. Left femoral artery
B. Left great saphenous vein
C. Bronchial arteries
D. Left external iliac vein
E. Right atrium
F. Pulmonary trunk
G. Left atrium

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