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Special Issue*: Threshold Concepts and Conceptual Difficulty*

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GUEST EDITORS' PREFACE

> We are an entangled species. We are not to be unknotted easily. When we turn our backs on difficulty … we turn our backs on who we are.
>
> Howard Jacobson *In Praise of Difficulty* 2016

This special issue of the PESTLHE journal addresses issues arising from the conceptual difficulty that students face in their disciplinary studies and programmes of professional development in higher education. Such encounters with difficulty – conceptual, affective, ontological – and the pedagogical and curricular interventions that teachers may identify to assist their students, are central to the Threshold Concepts analytic framework of learning (Meyer & Land 2003). The Threshold Concepts Framework (TCF) is premised on the notion that, in all disciplines, there are certain concepts, or certain learning experiences, which are akin to passing through a portal, permitting the learner to enter new conceptual territory in which things formerly not perceived are brought into view. These learning thresholds are often the points at which students experience difficulty. The TCF is a transformative approach to learning, assuming that, in a process of becoming, knowledge new to the learner needs to be troublesome in order to provoke new ways of seeing, and a letting go of their prevailing view. As Dewey (1986) once observed, 'The path of least resistance and least trouble is a mental rut already made. It requires troublesome work to undertake the alteration of

old beliefs.' Letting go of a prior view is always troubling, particularly when the new way of seeing, the new knowledge to be integrated, has not yet come fully into view and the learner finds him or herself in an in-between or transitional space which Meyer & Land (2003, 2005)characterise as a state of 'liminality'. This is the space of transformation, but can become a suspended state or 'stuck place' in which the learner wrestles with language and possible meanings to gain understanding, coherence or clarity. The learner may be in this space of transformation for considerable time. It may extend beyond the duration of the programme they are studying.

The transformation in understanding entails the integration of a new concept, and the integrative nature of the new concept tends to reconfigure the relations of other ideas already held in the learner's conceptual arsenal, their prevailing schemata, their prior learning. Successful integration results in a reformulation of the learners' frame of meaning. An analogy may be drawn with the integrating effect that the insertion of a specific piece in a jigsaw puzzle may have in rendering other proximal pieces meaningful in a new configuration (Land *in press*), bringing a new part of the picture into view.

> The threshold concept may be in the nature of a conceptual straw that breaks the camel's back – a piece in a jigsaw of concepts that causes them to coalesce and produce a step change in perception. (Land et al 2014 pp 208-209).

They need to be able to cope with their own oscillating behaviour within the liminal space as they strive for understanding. They need, further, to believe that the threshold will be crossed and that they are capable of crossing it. They need to be able to envision themselves, even if not clearly, occupying a new space beyond the threshold. In short, they need to have the psychological coping strategies that enable them to deal with the difficult and uncertain liminal phase and to accept that it will take time and effort to find their way through it (Rattray 2016 p. 73).

Such conceptual gateways have been characterised in earlier work (Meyer& Land 2003,2005) as *transformative* (occasioning a significant shift in the perception of a subject), *integrative* (exposing the previously hidden inter-relatedness of something) and likely to be, in varying degrees, *irreversible* (unlikely to be forgotten, or unlearned

only through considerable effort). They are also frequently *troublesome*, for a variety of reasons, not least the letting go of prior learning and reformulation of the learners' frame of meaning mentioned earlier. Depending on discipline and context, knowledge might be troublesome because it is ritualised, inert, conceptually difficult, alien or tacit, because it requires adopting an unfamiliar discourse, or perhaps because the learner remains 'defended', resisting the inevitable shift in subjectivity that threshold concepts initiate (Meyer & Land 2005). Encounters with a new or changed discourse during conceptual transformation may further compound difficulty.

The great majority of the articles in this special issue were first presented at the 5th International Biennial Conference on Threshold Concepts held at Collingwood College in the University of Durham from 9th–11th July 2014. Enjoying the uncharacteristic sunshine of a Northern English summer, beneath the towering silhouettes of Durham's thousand year old Cathedral and Castle, 102 delegates from 18 countries presented their findings over an intensive three days of deliberation and debate. These papers, which complement the edited volume published by Sense and named after the conference, *Threshold Concepts in Practice* (Land, Meyer & Flanagan 2016), add to the burgeoning collection of available resources on Threshold Concepts scholarship. They are further illustration of the ways in which the Thresholds Framework is currently employed in contexts of practice. The papers lend themselves to multiple categorisations but are grouped here under four broad headings of professional practice, issues of identity, curriculum design and the teaching of STEM subjects.

Professional practice

Given the theme of the 5th International Biennial Conference, it was not too surprising that many of the papers employed the TCF to analyse aspects of student learning, conceptual difficulty, pedagogical approaches and curriculum design in their own disciplinary or professional contexts of practice. **Lillian Byrne-Lancaster**, for example, examines the placement-based learning experiences of social care students in Ireland and finds that such placements have the potential to act as a liminal experience where identity is reconstituted, from a layperson studying a discipline to a practitioner within an occupation. Recognising the integrative potential of placement-based learning she concludes that. although the experience is often troublesome – 'creating anxiety and concern about suitability, performance ability and practice effectiveness'— the

placements serve as spaces in which the students gain an 'insight lens' that can 'transform theory from a body of knowledge', assist their understanding of service user's lives and needs and act as 'a guide for intervention'.

Within medical education in England **Tracey Collett, Hilary Neve** and **Nicole Stephen** explore the use of audio diaries (via smart phones and secure drop box facilities) to investigate how medical students re-appropriate sociological ideas to medical settings and adopt new terminologies derived from their own student discourse, and to identify shortcomings in learning and points of conceptual difficulty. Employing threshold concept theory as a framework, this team derive important methodological and educational insights such as, for example, that 'clinician facilitated small group work can lead to profound shifts in the way that students think about medicine, particularly with respect to the act of being a doctor'. Their findings lead them to question whether certain social science concepts are introduced within the medical curriculum at too a high a level, perhaps overestimating the capacity of students to automatically cope with theoretical complexity. They find promising instances of student transfer of learning, reinforcing the implication that theory often has to be applied before it starts to makes sense. They also query whether the quality of 'boundedness' identified in threshold concept theory might need to be reconsidered in the context of so-called soft (and more contestable) sciences as opposed to their harder counterparts.

On the other side of the globe **Rhonda Fuzzard**, working within the Australian Vocational Education and Training (VET) sector, uses the TCF to explore the 'intellectual and personal changes' experienced by learners following Community Service Work programmes. In the context of threshold notions of 'oscillation' in liminal states, she reports on a paradoxical phenomenon wherein students record 'significant changes on one hand, yet seemed to deny any changes to what they considered to be their core beliefs and values, and appeared to be unaware of any contradictions in their positions'. She explores potential explanatory factors for such puzzling responses, considering the challenging nature of affective thresholds which require complex understandings of self, client and society at a conceptual level. She suggests that such transformations perhaps operate more in the nature of 'articles of faith which are more affective than cognitive, to be believed as much as understood (Atherton et al 2008 p.11)'.

Also working within an Australian professional context, in this case Occupational Therapy (OT), **Liz Springfield**, **Sylvia Rodger** and **Louise Gustafsson** report on a mixed methods research enquiry, drawing on qualitative and quantitative data, which investigated students' and academics' experiences of engagement with threshold concepts through authentic assessment tasks in undergraduate and graduate entry masters OT curricula. They conclude that authentic assessment activities can be designed and implemented to successfully engage students concurrently with multiple threshold concepts, whilst meeting institutional assessment and professional accreditation requirements. They also found that 'authentic assessment activities are an appropriate stimulus for evoking ontological shift as described by Land and Meyer (2010)'. Student response data indicated that journeys through liminal space were often recursive, with specific disjunctions in learning 'only inferred by their reference to strategies and scaffolds they used to support movement from these disjunctions'. The team are led to speculate that students' unwillingness to retreat from disjunctions in learning 'may have been attributable to the highly motivating nature of the authentic activities, with students identifying that this motivated them to persist when they encountered obstacles '.

Issues of identity

Entry into professional practice inevitably entails the negotiation of appropriate professional identities (Wenger 1998). **Aoife Prendergast**, investigating the professional development of 'social sphere practitioners' in Irish education, observes that:

> While 'beginning social sphere practitioners typically conceptualise the process of learning to teach as a cumulative acquisition of concrete technical and organizational skills' (McLean 1999, p. 59), it is the development of social sphere professionals' identity as professionals which is perhaps more critical to successful negotiation of the liminal space between student and professional within which they find themselves during undergraduate practice education programmes.

She views practice education itself as a liminal space, 'a professional "block" of real-life work experience' which can be considered a portal or threshold to a specific profession. Her application of the thresholds framework to practice education for future social sphere professionals suggests that student engagement in 'a participatory and democratic process truly embedded in core threshold concepts' may assist future practitioners in 'uncovering identities in their own practice' allowing them 'to work and engage in critical reflections through a cyclic process'. However her research also finds that practice education is a complex and shifting arena, presenting a 'constellation of challenges' which, in concert with the 'ever evolving complexities that exist in social sciences' cautions against any simplistic analysis or conclusion.

In the area of Life Sciences teaching in UK universities **Anne Tierney** examines the experience of 'teaching-only' academics as they encounter the requirement to engage with the scholarship of teaching and learning (SoTL). Though Life science academics are professionals in their own fields these teaching-focused academics are asked to conduct research in the completely different area of SoTL, 'with a literature that is impenetrable'. Such engagement often proves confusing and 'may offer particular challenges as individuals tackle material outside their disciplinary expertise'. The discourse and research methodology of SoTL may prove alien, such that 'confidence in data gathering, sense of identity may present barriers to engagement with SoTL to academics who are more comfortable within a positivist, quantitative paradigm'. Moreover the transformation required is expected with a much more compressed time frame than that normally expected for the acquisition of disciplinary expertise, such that 'it is easy to understand why life scientists fall back on disciplinary protocols when trying to do pedagogical research'. The research identifies and locates threshold concepts within this necessary ontological shift and concludes that the academics engaged in this transformation 'may well see the power of SoTL and pedagogy in transforming their roles, even before they fully understand it'.

Considering the experience of classroom instructors in US colleges and universities **Devon Thacker Thomas** and **Laura Border** bring a dual conceptual perspective of the threshold concepts framework and intersectionality to bear on the issue of diversity. This they view as 'a complex, multi-faceted reality, which all instructors confront and sometimes resist at various points in their careers'. Their research identifies a liminal

space of transformation in which graduate student teachers move 'from being a teacher who cannot deal with diversity to a teacher who can', yet one in which these classroom instructors find engaging with issues relating to their own and their students' identities difficult, troublesome and disorienting. The twin conceptual lenses of TCF and intersectionality revealed liminal phases of stagnation, engagement, transition and exit in relation to changed understandings identities regarding diversity. In terms of future professional development practice these researchers conclude that If graduate student instructors are unable to cross the threshold in their understanding of diversity from an intersectional perspective , 'in which one's statuses are not understood as independent of one another, but rather as they intertwine to create one's lived experiences' then students will ultimately be 'at a disservice'. More widely, they warn, failure to consider diversity through the lens of intersectionality will allow for the production and reproduction of inequality.

Marina Orsini-Jones, Elwyn Lloyd, Gwenola Bescond, Fiona Lee and **Raef Boylan** are a UK team working collaboratively with Mexican colleagues to help students cope with the new challenges in their working lives presented by global interculturalism and in order 'to equip them with the multimodal multiliteracies necessary to "read" this world'. They draw on Barnett's (2005) notion of 'supercomplexity' and cite Hemmi et al's (2009 p.29) observation that 'the communicative landscapes opened up by social media can be spaces of strangeness and troublesomeness to the academy, both epistemologically and ontologically'. The authors describe a large-scale international intercultural exchange between the United Kingdom and Mexico – the *MexCo Project* (Mexico-Coventry) – which involves both tutors and students. The latter engage in joint curricular activities designed to take them out of their comfort zones. They are required to confront their own 'otherness' through a dialogue with others, and to acquire the 'intercultural digital literacies' necessary for both academia and for the world of work, so that they may become 'critically operational' in a world of such complexity. This requires a significant conceptual challenge and ontological shift. The research team report that the data emerging from the analysis of the students' tasks and interactions online would appear to indicate that 'Intercultural Communicative Competence' (ICC) in online exchanges might be a candidate threshold concept.

Working as teachers of History in US higher education **Arlene Díaz** and **Leah Shopkow** identify a 'cognitive disjuncture' within the self-concept of future teachers of

history whom they encounter on their training programmes. Though these teachers in training will, admittedly, not be required to publish historical work in their own right, nonetheless they will be expected to teach their students 'how to think historically' that is, to do history themselves. These teachers, however, 'see "learning history" as something different from "doing history".' The authors locate this disjuncture in the problematic status that History as a subject has acquired over time in US schooling, whereby the discipline has become reduced to 'a base of facts' to be utilised as required by other 'more relevant disciplines' such as Social Studies. The upshot of this historical tendency is that History is seen less as a useful object of study in itself, and, equally worrying, that 'teachers no longer felt it necessary to teach with historical sources'. Such a perspective, these researchers contend, is directly at odds with how historians think and practise, i.e. 'as an analytical practice'. Surprisingly, and somewhat worryingly, the researchers find that university-level history studies does not shift the ways of thinking and practising as might be imagined. They analyse potential causes of this problem: over-dependence on the lecture format with emphasis on historical description rather than explanation and analysis, insufficiently explicit modelling of historical analysis, and large classes which prohibit opportunities to practise skills of analysis. Accordingly they identify two transformational thresholds to be faced by their students. The first is a conceptual transformation 'from seeing history as a fixed, single-stranded narrative created by historians gathering indisputable facts to seeing history as something created by historians as part of a contested intellectual discourse'. The second is an ontological shift from seeing their role 'as purveyors of these single-stranded narratives to students, who must memorize them' towards a richer conception as 'teaching the moves of historical thinking …and giving those students an opportunity to practise them at a junior level'.

Curriculum design

As threshold concepts and ontological shifts are identified, consideration must then be given to the modes of learning, teaching and assessment that might prove most effective in bringing about the desired transformations. What experiences might be

designed or redesigned into a particular curriculum to assist the processes of transformation required, and what holding environments or other forms of support might help students as they encounter liminal states? **Graham Barton** and **Alison James**, working in Arts environments in English universities, adopt a 'whole systems thinking' approach to course design, drawing on application techniques developed in LEGO® SERIOUS PLAY®. They view this as a new perspective, and a set of exploratory tools, for supporting students' grasp of Threshold Concepts. The approach, they find, assists learners in creating symbolic constructions to help negotiate liminal states, and as 'mediating artefacts for mapping the epistemological terrain of a discipline'. By using LEGO® or other materials these researchers find they can assist students in making 'metaphorical constructions' to assist learning transformations. In curriculum design they emphasise the merits of design thinking and whole systemic thinking to help 'design for purpose within complexity', and to design for 'emergence' so that the student might discover 'the dominant paradigms, and associated epistemes, practices, perceptions, and of course, threshold concepts within their field of study'. Their advocacy of employing embodied materials, often three dimensional and multisensory in nature, seems to offer a positive new methodological dimension to the Threshold Concepts Framework (TCF).

Dai-Ling Chen and **Julie Rattray**, working in British and Taiwanese higher education contexts, consider issues of curriculum design in the development of critical thinking. They identify the concept of critical thinking as a threshold comprising 'a web of complex dimensions', and determine these dimensions as the 5Cs of *change* (a process of movement), *contestedness* (involvement of different perspectives), *convergence* (integration of various notions), *contextualisation* (context sensitivity), and *challenge* (unceasing enquiry). They proceed to map these dimensions to the key characteristics of threshold concepts as identified by Meyer and Land (2005). They view critical thinking as both a threshold concept and a vehicle to develop threshold capabilities (Baillie et al 2013), in this instance in the context of media literacy programmes. These researchers employ the pedagogy of problem-based learning as a tool to support the development of critical thinking in the media literacy classroom and as a way of supporting students' mastery of the critical thinking threshold concept. However the approach involves participants engaging in teamwork as the individual students explored new understandings together, and the researchers draw attention to the complicating factor that in measuring any learning gain the constructivist nature of PBL

makes it difficult to eliminate the effects of interactions between team members and hence isolate the potential impact it had on individual participants. 'The ideas of others', they caution, 'might have been the trigger to reconsider, refine and justify their own opinions'.

In recent years Australian universities have begun introducing elements of formal coursework into doctoral programmes of study , often in combination with attendance and assessment requirements. With the introduction of greater structure into the PhD it has become less unusual to talk of a doctoral 'curriculum'. **Margaret Kiley** has researched the possible role of Threshold Concepts (TCs) in the related design and pedagogy of this 'emerging PhD curriculum', and undertook enquiry in three Australian research universities. She considered the formal or informal coursework encountered, usually, in the first 12 months of candidature. She measured the extent of inclusion – or omission – of potential TCs in this field that had already been identified in the literature. For example, each of the programmes investigated incorporated TCs of 'research paradigm, framework, knowledge creation/originality, theory and writing'. On the other hand, the TCs of 'argument/thesis, analysis, creativity and "doctorateness"' were not so evident in the case analysis. A notable anomaly was the omission of 'research integrity' as a TC despite its mandatory nature in all three programmes. Her research concludes with possible explanations for omission such as the misidentification of the original TCs, or that their importance comes into view only at a later point in the research process (i.e. beyond twelve months). 'The most likely reason', she surmises, 'is that this level of structuring the PhD curriculum is in its early stages and it will not be until evaluations and reviews have been undertaken that additional topics, possibly addressing the Threshold Concepts noted, are included'.

The New Zealand Teaching and Learning Research Initiative (TLRI) recently funded a two year higher education research project entitled *Moving Beyond the Threshold: Investigating Digital Literacies and Historical Thinking in New Zealand Universities*. Digital technologies are currently driving New Zealand's knowledge-based economy and influence assumptions about the nature and function of 21st century higher education curricula. The research team, comprising **Sydney J. Shep**, **Rebecca Lenihan**, **Donelle McKinley**, **Matt Plummer** and **Michael Dudding**, attempted to determine the relationship between digital literacies, threshold concepts, and

transformative learning outcomes in history-informed disciplines. Their focus was to gain insights into how digital pedagogies might improve student learning outcomes, promote transformative learning, inform students' and teachers 'understandings of the past, and foster autonomous learning in history-related subjects. A wider concern of the research was to gain evidence that 'can be used to inform public policy about future funding strategies for digital learning practices at universities, addressing where gaps exist in students' access to resources by demographic, subject matter, ethnicity, and gender'. Interim findings of the project indicate firstly that innovation was likely to be found amongst more junior staff with 'neither disciplinary nor institutional traction to make a difference', often working in isolation, with little opportunity for collaboration or dissemination. Secondly a need for greater understanding of the use and value of digital tools (as opposed to digital resources) was identified: 'the idea of using digital tools upon digital data for digital analysis was foreign territory'. To compound this, research findings to date suggest that improvement of critical thinking skills is not perceived as one of the main benefits of digital resource and tool use. Hence early conclusions seem to indicate that the creative deployment of digital technologies to promote critical thinking in the field of history teaching may itself amount to a learning threshold.

The 'Sweden Group' is a well established research collaboration in computing science between academics in Sweden, the UK and the USA and has published extensively to date on the nature of threshold concepts and conceptual difficulty in computing (see Flanagan 2017). The seven members of this research group**, Lynda Thomas**, **Jonas Boustedt**, **Anna Eckerdal**, **Robert McCartney**, **Jan Erik Moström**, **Kate Sanders** and **Carol Zander** build here on their earlier work on the idea of 'threshold skills' as a complement to threshold concept to examine the curriculum activity of designing software as a possible example of such a threshold skill. They investigated 35 software designs from students nearing completion of their programmes. Considering skill as a form of procedural knowledge and hence 'difficult or impossible to write down and difficult to teach …best taught by demonstration and best learned by practice' (Norman 1990, p. 58) they produce an interesting threshold skills counterpart to the original characteristics of threshold concepts (Meyer & Land 2003) differentiating them as *transformative, integrative, troublesome, semi-irreversible* and *associated with practice.* After setting students a challenging design task and interviewing them on their experience and understand of this process the researchers conclude that software

design is a threshold skill according to their revised definitions and also provoked liminal experiences for the students included in the study. Reversibility proved to be a complex notion in that 'there may be an issue with granularity: parts of the design process – fluency in computing language and software design notation and building a solution from those parts is semi-reversible and may need refreshing. But the ability to break down a problem into parts may be irreversible'. Practice was found to improve understanding, yet software design 'continues to be troublesome and to serve as a boundary marker in the computing field'.

Teaching of STEM subjects

STEM subjects (science, technology, engineering and mathematics) are often seen as foundations of the industrial and corporate world, and are seen as a skill-set that is in high demand by employers. STEM skills within an educated workforce are seen to contribute significantly to the global position of many of the world's leading economies, as well as the world's scientific and technological research. The subjects are often seen as challenging however. Hence it is not surprising to see contributions from practitioners and researchers within STEM subjects represented within this collection of papers concerned with threshold concepts and conceptual difficulty. Employed in the Canadian higher education sector **David Harrison** and **Ruxandra Serbanescu** work in the burgeoning research field known as Physics Education Research (PER). Their research is premised on a concern, long held in the Physics education community, 'that many of our students have fundamental misconceptions about the nature of the physical universe and our description of that universe using mathematical language'. Use of specialised diagnostic instruments such as the Force Concept Inventory (FCI) (Hestenes et al 1992) to identify such misconceptions confirmed the researchers' suspicions that 'many of our students have surprisingly wrong ideas'. Interestingly these researchers go on to discuss 'how at least some of these wrong ideas are threshold concepts'. The researchers employ a series of diagnostic instruments to attempt to measure the effectiveness of changed pedagogical approaches on the assumption that 'If what we were doing in our courses wasn't working in terms of the conceptual understanding of physics that we particularly value, then it seems obvious that we need to change our pedagogy'. In a series of engaging scenarios these researchers analyse the conceptual difficulty experienced by students when they

encounter three areas of understanding identified as threshold concepts in Physics, namely Newton's 1st Law, Uncertainty in Physical Measurements, and Experimental Uncertainty. The over-riding conclusion from these studies is that 'students do not learn best by being lectured to. The best learning occurs when students interact with each other, particularly when those interactions are based on conceptually based activities using a guided-discovery model of instruction'.

In an additional single-authored paper **Ruxandra Serbanescu** further pursues the notion of misconception as understood within Physics Education Research (PER). Such misconceptions are found to be 'incomplete, contradictory, stable and highly resistant to change'. To tackle such resistance PER methods seek to create states of cognitive dissonance within students of Physics, hence obliging them 'to confront and uproot their misconceptions'. This further study seeks to compare the findings of the Threshold Concepts Framework (TCF) with Physics Education Research into similar areas of conceptual difficulty, for example by undertaking a systematic comparison of experimental uncertainty formulation in TCs and Physics Education Research. The study also counterbalanced the mainly teacher-derived identification of TCs in the threshold concepts literature (subsequently checked against the students' experience) with an approach that asked students to identify the TCs. This latter approach gave rise to a clear student selection of three groups of troublesome concepts which comprised *potentials* (electric and magnetic), *boundary conditions* (for the electric or magnetic fields) and *fields* (electric and magnetic). Conceptual difficulty was found to arise for a number of reasons. For example with the concept of *magnetic potential*, the concept was found to be abstract, without presenting any opportunity for an intuitive breakthrough. It was made more troublesome through its being loaded with a heavy mathematical apparatus, and the fact that it had not been encountered previously. *Electric potential* was found to present a similar degree of abstraction derived largely from its mathematical formulation, whereas the concept of *Boundary conditions* was experienced as 'conceptually confusing', 'not flowing with the course', and not supported by the opportunity for practice problems in the textbook. The notion of *fields* had proved troublesome in the first year programme and was further aggravated in second year by the increased mathematical component. Interestingly, regarding understanding of the notion of *experimental uncertainty,* the findings of this new study bore remarkable similarity to those of an Australian study in the thresholds research undertaken on the same topic some years earlier (Wilson et al 2010).

A new addition to the study of TCs in STEM disciplines is provided by **Furqaan Yusaf.** He considers the mathematical topic of *Stokes' theorem*, which arises in vector calculus, as a candidate threshold concept. This theorem requires the use of multiple other concepts, such as line integrals, surface integrals, the curl of a vector field and the flux of a vector field, certain of which have been identified as TCs in their own right. He surveyed the experience of 98 students on his course and how they situated this concept in the landscape of their course on vector calculus. The flux of a vector field is a concept which is new to students on the course, as is the curl of a vector field, yet both these concepts have physical interpretations. The theorem appears particularly troublesome in that the flux of a curl of vector field, defies any such physical interpretation. Analogies with flow and fluidity break down and this presents a major challenge. The theorem is non-intuitive and the students reported 'how hard it was to visualise the problem'. In an integrative fashion Stokes' theorem 'funnels a number of core concepts into one idea'. Strong evidence of its transformative potential came out in the survey. One student noted that the theorem was 'key to understanding the rest of the course'. The students found it difficult to trace back the errors in their thinking, with the researcher concluding that 'the back and forth cycles of understanding and confusion which accompany troublesome knowledge is indeed present in Stokes' theorem'. The inquiry found that the theorem definitely plays 'a gateway role' in the teaching of students, and that 'opening up new levels of knowledge, and access to entire methods which are very commonly used in their degree relies on understanding this concept'. It becomes imperative for students to gain access to this unfamiliar discourse and to become 'comfortable with the idea of the flux of the curl of a field'. Being able to talk about mathematical problems in this way, the research found, 'opens up new methods for solving problems that cannot be attempted in any other way'. This research study gives rise to important pedagogical considerations. Prior signalling of the conceptual challenges that topics such as Stokes' theorem will present may have a positive effect on the study approach of students. 'Being forewarned of their complexity allows for better preparation, and anticipation of frustration can mitigate loss of motivation that sometimes accompanies troublesome knowledge'. Once these challenges are identified as such, he continues, 'this can feed back into adaptations of teaching which motivate, orientate and prepare the student in very educationally useful ways'.

The wider conceptual problem of how students might come to understand the nature of evidence in scientific disciplines is addressed by **Ros Roberts** who teaches and researches in the English higher education sector. Her research is concerned with the problem that although expertise in a discipline requires understanding its research, this often remains hard to articulate owing to the fact that research tends to encompass tacit understandings. 'How', she inquires, 'can we frame a curriculum based on tacit knowledge?' The challenge for teachers of scientific subjects in higher education is how to develop these components of expertise in their students. A compounding factor is that research practice is often iterative rather than linear practice and this renders complex any attempt at conceptual mapping of scientific research expertise. A tentative approach has been to seek to articulate 'concepts of evidence', which emphasises the knowledge-base inherent in the 'thinking behind the doing'. Such concepts have subsequently been validated against the work of experts in research and industry. The educational question then becomes 'If the concepts of evidence are considered as an extension to the disciplinary knowledge-base for the curriculum, how might the curriculum best be organised to include it?' Research undertaken at Durham in the UK has found that not only does an appreciation of the nature of evidence assist students in their own conduct of open-ended investigations, but that it also seems to help them frame better questions about the research of others. A powerful framework for understanding the concepts of evidence is provided which moves from evidence at the level of a *single datum,* to a *data set,* to *relationships between variables* (patterns in data), to *comparison* with other sources of data, to *wider economic and social pressures* influencing the design and conduct of an investigation, which might be possible sources of bias. It is argued that 'the many conventions associated with disciplinary practice … may be better understood once the underpinning understanding about evidence, implicit within these conventions, is addressed'.

A capacity to interpret and critically evaluate statistical information and stochastic phenomena in a range of contexts, with the complementary ability to articulate the implications of statistical evidence and the acceptability or otherwise of conclusions drawn from it, is widely recognised as a desired attribute in graduates of STEM subjects, as well as those of many other disciplines (Gal 2002). **Andrew Wills**, accordingly, teaching statistical thinking (to non-statistician) medics and scientists in an English university, investigates potential threshold concepts in the postgraduate

curriculum they are following. His research queries 'the elements of statistics these students need to learn and how they learn' and questions 'whether the content and balance of content in statistical units is restricting deeper levels of understanding'. He challenges a 'cookbook' curriculum approach 'where students are taught, in sequential fashion, a battery of statistical tests for different scenarios, each akin to a recipe'. This, he cautions, can lead to a 'stuffed' curriculum (Cousin 2006), 'rote learned and quickly forgotten'. His aim, rather, is to foster understanding of the underlying concepts and ways of thinking that contribute to statistical literacy – 'the underlying concepts that link all the methods and key aspects of interpretation and comprehension'. To pursue a better understanding of what the latter kind of curriculum might entail, he undertook a preliminary enquiry, using the threshold concepts framework (TCF) as the analytic tool for his investigations. Recognising that 'there are many troublesome concepts in statistics that are not threshold' (such as deriving estimators) he designed and administered a survey to two groups of his former students a group of academic colleagues with postgraduate qualifications in statistics and/or epidemiology. This preliminary survey indicated three potential areas where threshold concepts in statistics may exist – 'the nature of statistical inference and uncertainty; probability; and descriptive statistics'. Though further investigation will be required in these identified topics to refine understanding of the threshold status of various concepts, nonetheless the report concludes that 'greater statistical literacy and understanding among non-statisticians will most likely be achieved by ensuring that curricula accommodate time for learning concepts in depth rather than rote-learning a great many statistical tests'.

As guest editors we are pleased to have the opportunity to make this collection of papers widely available through the PESTLHE Journal. We would like to record our appreciation to the general editors at PESTLHE for their kind invitation to produce this special issue and for the excellent technical support we received from Glyn Wheeler at Durham University. We would, of course, also like to thank all the contributing authors to this special issue for their time, effort, patience and careful scholarship. We are indebted to you.

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