


Ecological theories of systems and contextual change in medical education

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INTRODUCTION Contemporary medical practice is subject to many kinds of change, to which both individuals and systems have to respond and adapt. Many medical education programmes have their learners rotating through different training contexts, which means that they too must learn to adapt to contextual change. Contextual change presents many challenges to medical education scholars and practitioners, not least because of a somewhat fractured and contested theoretical basis for responding to these challenges. There is a need for robust concepts to articulate and connect the various debates on contextual change in medical education. Ecological theories of systems encompass a range of concepts of how and why systems change and how and why they respond to change. The use of these concepts has the potential to help medical education scholars explore the nature of change and understand the role it plays in affording as well as limiting teaching and learning.

METHODS This paper, aimed at health professional education scholars and policy

makers, explores a number of key concepts from ecological theories of systems to present a comprehensive model of contextual change in medical education to inform theory and practice in all areas of medical education.

RESULTS The paper considers a range of concepts drawn from ecological theories of systems, including biotic and abiotic factors, panarchy, attractors and repellers, basins of attraction, homeostasis, resilience, adaptability, transformability and hysteresis. Each concept is grounded in practical examples from medical education.

CONCLUSION Ecological theories of systems consider change and response in terms of adaptive cycles functioning at different scales and speeds. This can afford opportunities for systematic consideration of responses to contextual change in medical education, which in turn can inform the design of education programmes, activities, evaluations, assessments and research that accommodates the dynamics and consequences of contextual change.

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INTRODUCTION

How we understand context as education scholars presents many challenges.¹ We often look to standardise and normalise medical education practices (typically in the interests of efficiency and quality assurance)^{2,3}; by contrast, we encourage and pursue diversity (often as a way of challenging bias and inequality).^{4,5} Although both approaches have value and both have an important role to play in medical education, they reflect an ideological tension. The experimental tradition tends to minimise the effects of context as ‘controlled variables’, whereas more social constructive approaches explicitly examine the contexts within which social phenomena occur.⁶ Similarly, efficacy research explores how a particular intervention works under controlled conditions, whereas effectiveness research focuses on how context changes the erstwhile efficacy of an intervention.⁷ Other developments, such as social missions,⁸ the growing focus on longitudinality and continuity in educational programmes,⁹ and the problems associated with global competencies,¹⁰ also suggest that context is an increasingly critical issue in medical education. This includes those contexts that are controlled by medical schools and those that are not, such as the contexts for clinical workplace-based learning.

The role of context in medical education becomes particularly important when learners move between contexts (e.g. clinical rotations and placements)¹¹ or when a given context is changing (e.g. merging two teaching hospitals).¹² The problem is not that contextual change has been ignored in scholarship, but rather that it has been addressed inconsistently and with a lack of common concepts.¹³ We therefore need ways to articulate and connect the various debates on contextual change in medical education. Ecological theories of systems provide a useful set of theoretical concepts and models that can help to address this long-standing problem. This paper, aimed at health professional education scholars and policy makers, draws on ecological theories of systems to present a comprehensive model of contextual change as a way of informing theory and practice in all areas of medical education.

BACKGROUND

A clinical training context is ‘a dynamic and ever-changing system that emerges from underlying patterns of patients, locations, practice culture and

health systems, medical education, and society, and from the unpredictable interactions between these patterns’.¹³ Not only do learners moving between training contexts encounter different patients, family members and health care providers, their learning is also influenced by the flux of the health care and educational cultures they participate in, the other learners in the training environment, and the health, social and cultural contexts of the community as a whole.^{11,14–17} This is not a new issue and different theoretical perspectives have been used to consider it.

For instance, although the default empirical stance has focused on controlling for contextual ‘interference’, there has been some exploration of the role of contextual change in medical education from a complex adaptive systems (CAS) perspective.^{18,19} Clinical medical education happens at the intersection between education and health care, which has also been described as a complex adaptive system.^{20,21} Indeed, medical education activities are often nested within a medical school, nested within a university, nested within a society that directs funding to education, supplies its learners, and then employs them as health care providers. Clinical medical education is also nested within a clinical health care setting, within a health care institution, within a health system, within a society that directs the funding to health care and supplies its patients. A shift upstream, even far upstream, can affect the context of medical education. Just as the damming of a river changes the ecology far downstream, so a change in society, leading to, say, reduced funding to universities or health care, can greatly impact the contexts that teachers and learners have to work in. However, although CAS theory is helpful in allowing us to model the non-linear and unpredictable nature of these training contexts, CAS does not explain how or why the system itself reorganises in response to change, nor does it consider differences between internally and externally initiated changes.

Another theoretical perspective is that of situated cognition, which considers knowledge and learning as arising from the interactions between people and the contexts within which they are situated.²² This in turn suggests that competence is as much bound to context as it is to the individuals to whom it ostensibly belongs.^{23,24} However, although this helps to problematise the phenomenon of how contextual change may impact competence, it intrinsically differentiates mind from context, seeing the latter only in terms of the former. Despite these different

forays into the issue of contextual change, we still struggle to respond meaningfully and systematically to its many challenges.^{10,13}

An alternative approach is to draw on concepts from ecological theories of systems (ETS). ETS consider ecological systems and why and how they change or respond to change. We should be clear that ETS include, but are much broader than, Bronfenbrenner's topological 'ecological systems theory', which is primarily focused on human development.²⁵ ETS concepts describe the dynamic and emerging interactions and accommodations between individuals and their immediate settings.²⁵ As such, ETS concepts can illuminate how medical education contexts change, and how the individuals within them respond to change. In doing so we base our work on the following axioms:

- Competence is not an intrinsic characteristic of an individual; it is an enactment of optimal (or near-optimal) performance expressed in and for a particular context.²⁶
- Performance can be destabilised or eroded by changes in the individual.
- Performance can also be destabilised or eroded by changes in context or by the individual transitioning to a new context.

Although learning may be disrupted, it may benefit from these disruptions.²⁷ We can represent the effect of a contextual change disrupting an individual's performance followed by some form of recovery or accommodation (see Fig. 1). This shows the impact of this change in terms of disrupted

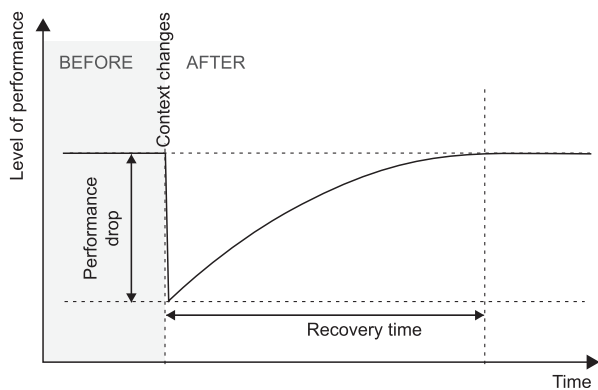


Figure 1 An individual professional's performance or that of a team may be negatively impacted by a change in their working context. The extent of this impact can be understood in terms of the depth of the loss of optimal performance and the time taken to recover performance.

performance (y-axis) and the time taken to recover (x-axis). We acknowledge that this is a simplification as there will typically be multiple aspects of performance in play at any one time,²⁸ along with multiple sources of influence and support.²⁹ We do not assume that the impacts of contextual change are always negative; indeed, different kinds of contextual change may have little impact on performance or they may lead to overall performance enhancement.

ECOLOGICAL THEORIES OF SYSTEMS (ETS) CONCEPTS

We can consider a number of core ETS concepts that can be used to model contextual change and individual responses to change in medical education (see also Table 1).

- *Ecological system*: the term 'ecosystem' was first coined in the 1930s to reflect a shifting scholarly focus from decontextualised biological entities to interdependent physical and biological elements within a particular environment.³⁰ 'Systems ecology' was developed as a way of considering the dynamics of ecosystems.³¹ The work of Holling and colleagues focused on how and why systems change, and how entities within systems respond to change, noting that 'hierarchies and adaptive cycles comprise the basis of ecosystems and social-ecological systems across scales'.³² An ecological system's living components (plants and animals) are its 'biotic factors' and the non-living components (climate, geography and physical environment) are its 'abiotic factors'. Ecological systems typically consist of multiple interdependent biotic and abiotic components. Socio-ecological systems also involve 'socio-cultural factors'.
- *Adaptive cycles*: ecological systems are dynamic and cycle through short episodes of disruption and change followed by longer episodes of stability and consolidation. Holling described four stages in adaptive cycles: release, reorganisation, exploitation and conservation. When an ecosystem is disrupted it needs to reorganise to suit the new conditions. The ecosystem gradually coalesces around a particular configuration (exploitation) that over time precludes any other configuration (conservation).³³ The related concept of 'panarchy' reflects the nesting of larger and smaller adaptive cycles within an ecological

Table 1 Key concepts from ecological theories of systems and their application to medical education

ETS concept	Definition	Application of ETS concept in medical education
Biotic factors	An ecological system's living components	A medical education ecosystem's actors, such as its students, teachers, patients, administrators, etc.
Abiotic factors	An ecological system's non-living components	A medical education ecosystem's facilities, such as its buildings, books, computers, electronic patient record software, simulators, its funding and other sources of support, and its physical setting, such as the climate and physical geography, etc.
Socio-cultural factors	An ecological system's social and cultural components	The human-generated arrangements and circumstances of a medical education ecosystem, such as its curriculum, language, values, expectations, etc., often reflecting a system's particular history and circumstances
Adaptive cycle	The process through which an ecosystem responds to disruptive change. An adaptive cycle goes through stages of release, reorganisation, exploitation and conservation	A medical education ecosystem may, for instance, be disrupted by a major increase in the incoming class size. The release stage may involve an appraisal of its available resources and how they can be used. The reorganisation stage may involve changing the curriculum or reallocating resources. The exploitation stage involves 'working out the kinks' and finding a stable and sustainable way of teaching the larger class. The conservation stage is where the new configuration becomes 'the way things are done'
Panarchy	Smaller and faster adaptive cycles tend to be nested within (and are to some extent constrained by) larger and slower adaptive cycles.	A typical medical education ecological system includes smaller adaptive cycles (e.g. new cohorts of students or a new building) and larger adaptive cycles (curriculum reform or changes in professional practice) that are intrinsically coupled and interdependent
Attractors and repellers	Individual factors driving adaptive cycles within the system. Functionally similar, they only differ in terms of the direction of influence	Attractors in medical education ecosystems may include funding, skills and capacity of teachers, affordances of new instructional or medical technologies and a good reputation. Repellers may include the costs of current or proposed practices, faculty members' or learners' scepticism, bad publicity or a poor reputation. Greater student-teacher contact time may be an attractor for students but a repeller for faculty members with many other competing commitments
Basins of attraction	The equilibrium between the attractors and repellers around which an ecosystem establishes a relatively stable configuration	A medical education ecosystem needs to balance the provision of care, availability of funding, changing social values and regulatory processes such as accreditation. Differing 'basins of attraction' can help to explain why different medical education ecosystems may have different outcomes despite working from the same biomedical and educational bases
Stability, instability and disruption	Ecosystems are dynamic and subject to small non-disruptive changes all the time. Change becomes disruptive when the system needs to change to remain viable	Variations between patients, learners or preceptors, seasonal epidemics or changes in staff rosters do not tend to lead to major disruptions in medical education systems, whereas changes in public trust in the medical profession, labour disputes or changes in clinical practice can disrupt a system to the point where it takes on a new configuration. ^{38,46}

Table 1 (Continued)

ETS concept	Definition	Application of ETS concept in medical education
Resilience	The persistence of a system's relationships and functions in the face of change	Although medical education programmes have different learners in each cohort, they tend not to be disrupted by these changes and can therefore be said to be resilient to this kind of change.
Adaptability	The ability of an ecological system to respond to change or disruption so as to maintain the core functions of the system	A clinical training unit that is able to change its practice patterns to meet the needs of struggling learners is more adaptable than one whose clinical performance depends on a maintaining a fixed teaching and practice model
Transformability	The capacity to create a fundamentally new system state when changes make the existing system state untenable	A teaching hospital that can change its freestanding internship training to a university-affiliated family practice training in the face of phasing out of the internships displays transformability. ^{47,48} A school that develops a rural longitudinal integrated clerkship as a response to the challenges of traditional training at academic health science centres, ^{49,50} or as a way of meeting workforce problems, ⁵¹ or as a way of realising a social mission, ⁵² also shows transformability
Systems management	The ability of those within a system to maintain that system in the face of disruptive change	A medical education ecosystem may respond to emerging change in crisis mode (reactive) if it does not detect the coming change (passive) or take steps to mitigate it (active). For instance, a school that maintains good communications with its accreditors is more likely to anticipate changes in accreditation standards or expectations than one that does not
Hysteresis	Either the delay between a change in an ecosystem and its response to that change or a delay between when a change stops and when the system stops responding	A call for curriculum reform in medical education rarely leads to instant system change. Plans need to be made and changes need to be implemented, evaluated and adjusted over time

system where larger and often slower adaptive cycles constrain the smaller and faster ones.^{33,34}

- *Attractors and repellers:* adaptive cycles are driven by a range of different forces and influences, some of which can be 'attractors' and others 'repellers'.³⁵ Although we typically tend to focus on a single dominant attractor in an ecosystem, in practice ecological systems will usually have multiple changing attractors that drive both small and large adaptive cycles. Attractors and repellers are functionally similar (in that they drive adaptive cycles); they only differ in terms of the direction of influence relative to the factor or factors in a system they are influencing. An attractor or repeller within one adaptive cycle may function differently within another, and what functions as an attractor for one group may be neutral or a repeller for another. A cumulative concept of an

ecosystem's '*basin of attraction*' refers to the equilibrium between the attractors and repellers around which an ecosystem establishes a relatively stable configuration.

- *Systems management:* an ecosystem's stability is maintained dynamically by adjusting to change; everyday perturbations may temporarily and modestly destabilise it but not to the point at which it does not (or cannot) return to homeostasis. Other changes may destabilise a system to the point that it cannot regain homeostatic state, at which point it either establishes a new homeostatic state or it fails altogether.³⁶ Both social and biological ecosystems can be (to some extent) managed. Hilborn differentiated between reactive, passive or active systems management. Reactive management involves no explicit monitoring or evaluation and, as a result, those within the

system can only respond to change once its effects become apparent. Passive management involves explicit monitoring and evaluation so that the system can anticipate changes before their effects are apparent. Active management involves modelling the system and pre-emptively making it less prone to disruptive change.³⁷

- *Responses to change:* most systems are in a constant state of flux. However, although some change is essential to system sustainability, other change can be disruptive. Ecological theories of systems model different phenomena in the way that systems respond to disruptive change.
 - i *Resilience:* Holling defined an ecological system's '*resilience*' as the persistence of its relationships and functions in the face of change.³² More recently, Walker defined resilience as 'the capacity of a system to absorb disturbance and reorganise while undergoing change so as to retain essentially the same function'.³⁸ Gunderson differentiated between '*engineering resilience*' where a system that has been disturbed returns to exactly the same state it was in before the disturbance, and '*ecological resilience*' where a system has multiple stable states that it may move between when disturbed.³⁹
 - ii *Adaptability:* is the ability of an ecological system to respond to change or disruption so as to maintain the core functions of the system. From a human systems perspective, adaptability is the collective capacity of individuals in a system to manage change.³⁸ From the ecological systems perspective, resilience is a performative quality of a system as a whole, whereas adaptability is the means by which participants in a system contribute to its resilience.
 - iii *Transformability:* is the capacity to create a fundamentally new system when ecological, economic, social or political conditions make the existing system untenable.³⁸ Although adaptability is about retaining a modal system state and function, transformability is about establishing a new stable state but with a different function once the old state becomes untenable.

Central to these concepts is the idea that a system in equilibrium has a stable function, and that this function can be disrupted and may either be retained or recovered, or transformed to a different function.

- *Hysteresis:* ecological systems rarely respond instantly to disruptive influence; there is typically a delay between the start of the disruption and the system's response to it, and then, after the source of disruption has gone, there is a delay before the system's response ends. This behaviour is called '*hysteresis*', which may occur at the level of an individual, class, school or whole educational system. Moreover, the response to change may be influenced by recent adaptations a system had to make. Hysteresis depends both on the speed of change and the speed of response. Some change is slow (such as the shifting male to female ratio in medical school classes), whereas other change is more rapid (such as funding cuts or social unrest). The speed of change and the speed at which a system is able to respond will generally mirror each other; the more a system's response falls behind the changes that require it, the greater the hysteresis effect.

DISCUSSION

Using concepts from ecological theories of systems allows us to go beyond the descriptive capabilities of complex adaptive systems theory¹⁸ to help the medical professions education community to understand how and why the same contextual change in different settings can lead to different system and individual responses. Indeed, understanding medical education ecosystems using the concepts we have outlined in this paper can help us to better understand how these ecosystems work, how fast and in what ways they are changing, how smooth or irregular the changes are, and how different adaptive cycles interact. This affords opportunities for educational scholars working directly with educational systems to expand the theoretical basis for their work. Furthermore, a better understanding of the systems dependencies of individual teachers and learners has the potential to help all scholars in the field.

ETS concepts can also allow us to compare and contrast different responses to contextual change, such as: avoiding or minimising the impact of contextual change (reflected in the pursuit of continuity in medical education)⁹; increasing how much change it takes to disrupt a system (such as engaging students in quality improvement projects)⁴⁰; reducing the effort and time required

for systems to recover following disruption (such as preparing learners to deal with medical errors)⁴¹; or increasing system adaptability in response to disruptive change (such as the loss of key faculty members or resources). We can also more easily compare proactive responses to change (preparing learners by developing their skills in responding to change in general) with reactive responses (helping learners to respond to specific changes as they are happening or in their aftermath). Where contextual change cannot be fully controlled (as is often the case), we may be better investing in increasing the resilience and adaptability of medical education systems. ETS also highlights the option of managed adaptation rather than resistance to or recovery from change.

For instance, we can use ETS concepts to identify different strategies for reducing or mitigating the negative or detrimental impact of contextual change in medical education. More specifically, we might seek to:

- Reduce learner exposure to contextual change by making changes in a training programme less frequent or less abrupt, or by designing training contexts to be less prone to disruptive change. We may also ask; to what extent is disruptive change a good thing and should we always be trying to avoid it?
- Increase or enhance medical education system resilience in the face of disruption through its biotic factors (such as helping faculty members to be more adaptable in their approaches to teaching), its abiotic factors (such as making classrooms more configurable for different purposes) or its socio-cultural factors (such as making it easier to make changes to the curriculum), or through various combinations of these factors.
- Increase or enhance individual and collective stability by helping learners to sustain their performance in the face of disruptive change (such as increasing individual awareness of the attractors and repellers impacting their performance) or to recover more efficiently as and when their performance is disrupted (such as developing a more deliberate approach to learning, or knowing when to ask for help).
- Reduce hysteresis both in responding to change (such as making curricular structures less rigid) and in ending responses to changes at the right time (such as using continuous evaluation and feedback loops in remediation).

However, it is important to note that there are limits to which change can or should be mitigated, particularly given the panarchic nature of change and disruption. After all, medical education is nested in larger systems of universities, health systems and societies, over which it has little or no control; disruptive change in any of these broader systems is likely to lead to disruptive contextual change in medical education ecologies. For instance, changing societal attitudes towards gender and disability have led to significant changes in admissions and accommodations in medical education in recent decades. The concept of transformability (respond to change by changing functions) rather than resilience (retaining original functions despite contextual change) is central to this point. Although it could be said that medical education is resilient at the macro level (it has continued to produce doctors despite changing circumstances), it has shown a significant degree of transformability in areas such as social missions, distributed medical education, instructional technology and pedagogical methods, and the expected competencies of a graduating doctor.

Another key question that arises from the use of ETS concepts is whether, in developing learner resilience during transitions, it is more important to focus on improving learner responses to contextual change than it is to seek to protect them from contextual change.⁴² After all, learners may benefit from being exposed to contextual change that is carefully monitored so as to not be overwhelming if it helps them to develop skills in adapting to change once they are in practice. If disrupting existing practice and reinventing it to accommodate new learning is central to professional development, then we might need to look at dips in learner performance more positively. Similarly, we might seek to build on opportunities to disrupt our faculty members in the interests of their professional development rather than trying to keep them in their comfort zones.

In exploring an ecological perspective on contextual change in medical education, we should be clear that we work with 'social ecologies' where participants' actions are informed by their underlying motives, identities, cultures and other personal and social factors. Participants in social ecologies 'influence resilience, either intentionally or unintentionally'.³⁸ Their collective capacity to manage their system's resilience determines the extent to which they can resist flipping to less desirable system configurations, or can recover more desirable configurations following

disruption.³⁸ Moreover, responses may not be an internalisation of the changing circumstances; responses may involve resistance (rejecting, ignoring or trying to reverse contextual change or its impacts) or compliance (adapting to change externally but dissenting internally).⁴³ Responses may move between these states over time or in response to different kinds and degrees of change.

As much as there is great potential in ETS as a way of modelling contextual change in medical education, we should acknowledge a number of its limitations. Firstly, ETS isn't a single framework or coherent body of theory; it is a moving, changing body of intersecting theories with no single dominant model or framework. Indeed, there are many systems theories (soft, hard, human, technical, etc.)⁴⁴ and we make no claims for or against the utility of concepts from these other systems theories and discourses. We should also be clear that we are not advocating that other theoretical positions, such as CAS theory, be abandoned in favour of ETS. After all, although the origins of ETS predate CAS theory, they have more recently built on principles of CAS to get to the how and why questions regarding change in ecological systems. Our thesis is that, by employing concepts of how and why systems change and how and why they respond to change, medical education researchers and planners can more directly explore the nature of change and understand the role it plays in affording as well as limiting teaching and learning. We should also be clear that, although we have focused on contextual change as a potentially disruptive influence on medical education systems, contextual change may be a catalyst for constructive improvements in medical education systems. For instance, the growth of social accountability, service learning and patient safety in medical education are constructive responses to earlier problems and shortcomings in medicine and medical education.

We also acknowledge that our focus has been on the translation of concepts from one field to another. We have not tested the utility and applicability of the concepts or any alternatives to this approach beyond asserting similarities and applications in medical education scholarship. This will need to be a focus of subsequent studies. Last but not least, we acknowledge that in translating this work to practice, we have yet to identify precisely what proxies or measures of change and the impact of change on competence we might use to generate the kinds of performance curves we have set out as illustrations in this paper. For instance, do we need to identify actual failures or suboptimal practice, or is it sufficient (or even more important) to

capture the sense of disorientation, diminished confidence or other cognitive responses to contextual change? Clearly there is much work to be done in unpacking and exploring the issues we have raised here.

CONCLUSIONS

Given the intrinsically fluid nature of context in medical education and the potential disruptions to performance from contextual change,^{11,45} it is important that we model how medical education and workplace systems as a whole and how the individuals within them respond to these changes. Ecological theories of systems provide a series of concepts and models that allow us to do so. This can in turn inform the design of education programmes, activities, evaluations, assessments and research that accommodates and even makes use of (rather than disregards) the dynamics and consequences of contextual change.

Contributors: RE led the development of the paper (substantial contributions to the conception and design of the work, including identifying and analysing literature sources, drafting the work and revising it critically for important intellectual content). She gave final approval of the submitted version and she has agreed to be jointly accountable for all aspects of the work, including ensuring that any questions related to the accuracy or integrity of any part of the work will be appropriately investigated and resolved. JB made substantial contributions to the conception of the paper and writing and revising it. She gave final approval of the submitted version and she has agreed to be jointly accountable for all aspects of the work, including ensuring that any questions related to the accuracy or integrity of any part of the work will be appropriately investigated and resolved. PWT made substantial contributions to the conception of the paper and writing and revising it. He gave final approval of the submitted version and he has agreed to be jointly accountable for all aspects of the work, including ensuring that any questions related to the accuracy or integrity of any part of the work will be appropriately investigated and resolved.

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REFERENCES

- 1 Eraut M. Non-formal learning and tacit knowledge in professional work. *Br J Educ Psychol* 2000;**70** (1):113–36.

- 2 Frank JR, Snell L, Sherbino J, eds. *CanMEDS 2015 Physician Competency Framework*. Ottawa: Royal College of Physicians and Surgeons of Canada 2015.
- 3 General Medical Council. *Tomorrow's Doctors: Outcomes and Standards for Undergraduate Medical Education*. London, UK: General Medical Council 2009.
- 4 Boylan M, Grant RE. Diversity and professional excellence. *J Natl Med Assoc* 2004;**96** (10):1354–62.
- 5 Girotti JA, Park YS, Tekian A. Ensuring a fair and equitable selection of students to serve society's health care needs. *Med Educ* 2015;**49** (1):84–92.
- 6 Flyvbjerg B. *Making Social Science Matter: Why Social Inquiry Fails and How It Can Succeed Again*. Cambridge, UK: Cambridge University Press 2001.
- 7 Flay BR, Biglan A, Boruch RF, Castro FG, Gottfredson D, Kellam S, Moscicki EK, Schinke S, Valentine JC, Ji P. Standards of evidence: criteria for efficacy, effectiveness and dissemination. *Prev Sci* 2005;**6** (3):151–75.
- 8 Mullan F, Chen C, Petterson S, Kolsky G, Spagnola M. The social mission of medical education: ranking the schools. *Ann Intern Med* 2010;**152** (12):804–11.
- 9 Ellaway RH, Graves L, Cummings B-A. Dimensions of integration, continuity, and longitudinality in clinical clerkships. *Med Educ* 2016;**50** (9):912–21.
- 10 Whitehead C, Kuper A, Hodges B, Ellaway RH. Conceptual and practical challenges in the assessment of physician competencies. *Med Teach* 2015;**37** (3):245–51.
- 11 Teunissen PW. Experience, trajectories, and reifications: an emerging framework of practice-based learning in healthcare workplaces. *Adv Health Sci Educ Theory Pract* 2015;**20** (4):843–56.
- 12 Wen C, Hays CW. Medical education in China in the postcultural Revolution era. *N Engl J Med* 1975;**292** (19):998–1005.
- 13 Bates J, Ellaway RH. Mapping the dark matter of context: a conceptual scoping review. *Med Educ* 2016;**50** (8):807–16.
- 14 Betancourt JR. Cross-cultural medical education: conceptual approaches and frameworks for evaluation. *Acad Med* 2003;**78** (6):560–9.
- 15 Irby DM, Wilkerson L. Educational innovations in academic medicine and environmental trends. *J Gen Intern Med* 2003;**18** (5):370–6.
- 16 Fish D, Coles C. *Medical Education: Developing a Curriculum for Practice*. Maidenhead, UK: Open University Press 2005.
- 17 Dwyer J, Tsai DFC. Developing the duty to treat: HIV, SARS, and the next epidemic. *J Med Ethics* 2008;**34** (1):7–10.
- 18 Mennin S. Complexity and health professions education: a basic glossary. *J Eval Clin Pract* 2010;**16** (4):838–40.
- 19 Mennin S. Self-organisation, integration and curriculum in the complex world of medical education. *Med Educ* 2010;**44** (1):20–30.
- 20 Mason M. Complexity theory and the philosophy of education. *Educ Philos Theory* 2008;**40** (1):4–18.
- 21 Stacey RD, Mowles C. *Strategic Management and Organisational Dynamics: The Challenge of Complexity to Ways of Thinking About Organisations*, 7th edn. Harlow, UK: Pearson Education 2016.
- 22 Brown JS, Collins A, Duguid P. Situated cognition and the culture of learning. *Educ Res* 1989;**18** (1):32–42.
- 23 Epstein RM. Assessment in medical education. *N Engl J Med* 2007;**356** (4):387–96.
- 24 Wass V, Archer J. Assessing learners. In: Dornan T, Mann K, Scherpbier A, Spencer J, eds. *Medical Education: Theory and Practice*. Edinburgh, UK: Elsevier 2010;229–55.
- 25 Bronfenbrenner U. *The Ecology of Human Development: Experiments by Nature and Design*. Cambridge, MA: Harvard University Press 1979.
- 26 Frank JR, Snell LS, Cate OT et al. Competency-based medical education: theory to practice. *Med Teach* 2010;**32** (8):638–45.
- 27 Kilminster S, Zukas M, Quinton N, Roberts T. Preparedness is not enough: understanding transitions as critically intensive learning periods. *Med Educ* 2011;**45** (10):1006–15.
- 28 ten Cate O, Scheele F. Competency-based postgraduate training: can we bridge the gap between theory and clinical practice? *Acad Med* 2007;**82** (6):542–7.
- 29 Pusic MV, Boutis K, Hatala R, Cook DA. Learning curves in health professions education. *Acad Med* 2015;**90** (8):1034–42.
- 30 Willis AJ. The ecosystem; an evolving concept viewed historically. *Funct Ecol* 1997;**11** (2):268–71.
- 31 Patten BC. Systems ecology: a course sequence in mathematical ecology. *Bioscience* 1966;**16**:593–8.
- 32 Holling CS. Resilience and stability of ecological systems. *Annu Rev Ecol Syst* 1973;**4**:1–23.
- 33 Holling CS, Gunderson LH, Ludwig D. In quest of a theory of adaptive change. In: Gunderson LH, Holling CS, eds. *Panarchy: Understanding Transformations in Human and Natural Systems*. Washington, DC: Island Press 2002;3–22.
- 34 Gotts NM. Resilience, panarchy, and world-systems analysis. *Ecol Soc* 2007;**12** (1):24. <http://www.ecologyandsociety.org/vol12/iss1/art24/>. [Accessed 11 December 2016.]
- 35 Vandermeer JH, Goldberg DE. *Population Ecology: First Principles*, 2nd edn. Princeton, NJ: Princeton University Press 2013.
- 36 Scheffer M, Carpenter S, Foley JA, Folke C, Walker B. Catastrophic shifts in ecosystems. *Nature* 2001;**413** (6856):591–6.
- 37 Hilborn R. Can fisheries agencies learn from experience? *Fisheries* 1992;**17** (4):6–14.
- 38 Walker B, Holling CS, Carpenter SR, Kinzig A. Resilience, adaptability and transformability in social-ecological systems. *Ecol Soc* 2004;**9** (2):5.
- 39 Gunderson LH. Ecological resilience - in theory and application. *Annu Rev Ecol Syst* 2000;**31**:425–39.

- 40 Wong BM, Levinson W, Shojania KG. Quality improvement in medical education: current state and future directions. *Med Educ* 2012;**46** (1):107–19.
- 41 Lester H, Tritter JQ. Medical error: a discussion of the medical construction of error and suggestions for reforms of medical education to decrease error. *Med Educ* 2001;**35** (9):855–61.
- 42 Teunissen PW, Westerman M. Opportunity or threat: the ambiguity of the consequences of transitions in medical education. *Med Educ* 2011;**45**(1):51–9.
- 43 Kelman H. Compliance, identification, and internalization: three processes of attitude change. *J Conflict Resolut* 1958;**1**:51–60.
- 44 Checkland P. *Systems Thinking, Systems Practice*. Chichester, UK: Wiley 1981.
- 45 Erickson F, Schultz J. When is a context? Some issues and in the analysis of social competence. In: Cole M, Engeström Y, Vasquez O, eds. *Mind Culture and Activity: Seminal Papers from the Laboratory of Comparative Human Cognition*. Cambridge, UK: Cambridge University Press 1997;22–31.
- 46 Brosnan C, Turner BS. *Handbook of the Sociology of Medical Education*. Abingdon, UK: Routledge 2009.
- 47 Taylor IL. Hurricane Katrina's impact on Tulane's teaching hospitals. *Trans Am Clin Climatol Assoc* 2007;**118**:69–78.
- 48 Fabreau G, McKinney B, Agarwal A, Morrison R, Rajaprakash M. Disaster Management Plans in Canadian Medical Schools. Canadian Federation of Medical Schools (Rev 1), 2015. <http://www.cfms.org/files/position-papers/2015%20CFMS%20Disaster%20Management.pdf>. [Accessed 14 September 2016.]
- 49 Irby D. Educational continuity in clinical clerkships. *N Engl J Med* 2007;**356**:856–7.
- 50 Hirsh DA, Ogur B, Thibault GE, Cox M. "Continuity" as an organizing principle for clinical education reform. *N Engl J Med* 2007;**356** (8):858–66.
- 51 Worley P, Silagy C, Prideaux D, Newble D, Jones A. The parallel rural community curriculum: an integrated clinical curriculum based in rural general practice. *Med Educ* 2000;**34** (7):558–65.
- 52 Ellaway RH, O'Gorman L, Strasser R, Marsh DC, Graves L, Fink P, Cervin C. A critical hybrid realist-outcomes systematic review of relationships between medical education programmes and communities: BEME Guide No. 35. *Med Teach* 2016;**38** (3):229–45.

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