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The power of deep time in geoscience education: linking 'interest', 'threshold concepts' and 'self-determination theory'

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ABSTRACT. Geological time is a pivotal concept in geological education, yet it often fails to be included explicitly in UK school curricula. The careful application of existing educational theory can assist geoscience educators in their role of enhancing learners' understanding of Earth's deep history and providing a deep time conceptual framework for environmental change education. Three bodies of theory are reviewed with teachers' imperatives in mind. These relate to interest, conceptual change and motivation. First, the psychological construct of interest can be analysed in terms of situational and individual interest. Second, threshold concept theory is presented as a recent addition to conceptual change theory. Third, learner motivation is examined in the context of self-determination theory. Such bodies of educational theory are rarely progressively cumulative because new ideas are typically presented in a relatively independent fashion. Further fragmentary theorising may generate minimal new insight, but combining such bodies of theory into a coherent whole may provide greater assistance to educators in their planning, teaching and assessment. Many such teachers have strong subject loyalties and orientations, so this three-fold blend is developed in the context of geoscience, using deep time as the dominant threshold concept. A 3-by-4 cellular model combines the key elements of interest and self-determination theory in relation to the threshold concept of deep time. Teachers can use the model to plan curricula or to diagnose learner motivation and cognition.

Key words: geoscience, threshold concepts, interest, motivation, geological time.

INTRODUCTION

This paper is integrative, being set in the context of geoscience education in general and geological (deep) time education in particular. It brings together three strands of intellectual endeavour which are reflected in three bodies of literature. These may be labelled, respectively: 'interest'; 'conceptual change'; and 'human motivation and psychological needs'. The first relates to the body of literature which analyses the implications for learning of various facets of learners' interest (Hoffmann et al., 1998). The second, on conceptual change, is here restricted to one particular and newly emerging body of theory which seeks to analyse 'threshold concepts', usually in the context of adult (higher) education (Land et al., 2008). The third strand also here is represented by a small element within the huge motivation literature: 'self-determination theory' (SDT) (Deci and Ryan, 2000).

The literature base of all three strands has expanded in recent years and each provides opportunities to enhance geoscience education. First, learning-focused research into interest expanded rapidly through the 1980's and 1990's with the emergence of new research groups, international conferences and symposia, research articles (both empirical and theoretical) and substantial compilations (Hoffmann et al., 1998; Renninger et al., 1992) which have since become standards. Second, although the huge literature on conceptual change has been expanding steadily for over 40 years, threshold concept (TC) theory is very new: the label was first used in 2002 (Meyer and Land, 2003). Finally, self-determination theory has developed over 35 years from early work on intrinsic and extrinsic motivation by Edward Deci and Richard Ryan (and their collaborators) at Rochester University (NY) (Deci et al., 1991).

Typically in education and other social sciences, as distinct from geoscience and the natural sciences, bodies of theory tend be cumulative, not necessarily progressive and rarely cohesive. Typically, new ideas or models are proposed, evaluated and refined in different contexts over a period of years. Theory is developed locally (not geographically 'local', but in terms of workers in that field) and generally on an *ad hoc* basis, according to availability of research funds and/or researchers' interests. Some of this theory is shown to be so powerful in its explanation and prediction that it becomes widely disseminated and accepted, impacting on classroom practice and academic enquiry over many decades (Bruner, 1966), or seems destined to do so (Ainley et al., 2002a). Much of it, however, becomes lost from the collective research consciousness or, at best, is occasionally revisited by later

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researchers who may draw on it for inspiration or comparison. Thus we have, for example, "*the problem of the welter of theories of learning that have accumulated over the years, without attempts to integrate them into a general theory. There is little evidence of cumulative development in theory to incorporate aspects of learning that earlier theories have correctly identified*" (Entwistle, 2007, p. 2). Although this particular 'welter' problem relates most closely to only one of my three bodies of theory, conceptual change, it can also be detected in the literature on human motivation and (rather less so) interest.

It follows from the above assertions that the addition of yet more theory to each of these three categories is unlikely to advance educational practice substantially. It is proposed, therefore, that integration of existing theory is needed. The imperative, therefore, is for current ideas which have been tried and tested and not (yet?) found wanting to be combined in such a way that teachers (and all educators) and subsequent researchers may gain new and beneficial insight into pertinent issues. Awareness of the relevance of such theory to teaching and learning is certainly present among educators: they are conscious of matters such as: (i) their learners' interests; (ii) how concepts are learned and; (iii) the psychology which underpins learner motivation. Furthermore, many educators have strong allegiances to their academic subjects and prefer to relate to generic educational matters in that context: hence the focus on geoscience and deep time in this paper.

STRAND 1: INTEREST

Interest is a psychological construct concerning motivation, extensively analysed in relation to a person's learning, attainment, attention, recognition, persistence, effort, self-efficacy and emotions (Renninger et al., 1992). It has both cognitive and affective dimensions, it has biological roots and it always links a person with external content. Thus "*the potential for interest is in the person but the content and the environment define the direction of interest and contribute to its development. Thus, other individuals, the organization of the environment, and a person's own efforts, such as self-regulation, can support interest development … [and]… interest is always content specific and not a predisposition that applies across all activities*" (Hidi and Renninger, 2006, p. 112).

Situational interest refers to the interest which is experienced by a learner immediately before, during and after the learning process. It is generated by many factors, not least being the nature of the learning activities and they way they are presented by the teacher. It includes all the visual, aural and other stimuli which might influence the learner's affective responses. Situational interest arises from the learner's context or immediate surroundings and has been exhaustively researched in recent decades under various guises. Chen et al. (2001) define it as "*the appealing effect of an activity or learning task on an individual, rather than the individual's personal preference for the activity*" (p. 384). Situational interest is typically transient, temporary and provisional, and teachers are adept at fostering it (Schraw and Lehman, 2001). The transient nature of situational interest is often overlooked by teachers, or assumed to continue into the future with no further intervention. However, the processes by which situational interest can develop into a more substantial and long-lasting affect with time are complex (Hidi and Renninger, 2006).

Individual interest (or 'personal interest') is more secure than situational interest, comprising the pre-existing interest or disposition felt or expressed by learners which they bring to a new learning experience. Such interest is typically long-lasting, robust and sometimes idiosyncratic. Schiefele (1992) conceptualises it as "*a domain-specific or topic-specific motivational characteristic of personality, which is composed of feeling-related and value-related valences*" (p. 154). Ainley et al. (2002b) offer a more pithy definition of individual interest: "*relatively stable orientations that have developed over time*" (p. 412). Hidi and Harackiewicz (2000) make an explicit link between interest and "increased knowledge, value, and positive feelings" (p. 152).

How can transient short-term situational interest be converted into robust individual interest and what links interest with attainment? First, it has been shown that individual interest is a better predictor of secure learning than is situational interest. In their study of 490 German secondary school students, Randler and Bogner (2007) found that "*interest prior to the unit had the strongest impact on subsequent learning (class test) and retention. ….it may reflect a kind of individual interest in the form of a predisposition that persists over time, and individual interest may have a stronger impact on learning, whereas situational interest reflects short-term measurements*" (p. 475). Second, the pedagogical processes by which an initial 'triggered situational interest' might be progressed towards a 'well-developed individual interest' are addressed by some authors, with reference to 3-stage (Krapp, 2007) and 4-stage models of interest development (Hidi and Renninger, 2006).

STRAND 2: THRESHOLD CONCEPTS

Threshold concept theory has arisen within higher education, although some authors apply it to younger students' learning (Ashwin, 2008). A TC is a pivotal idea within an academic discipline which, on acquisition by the learner, provides a transformed view of that discipline. Threshold concepts are, therefore, 'transformative' (Entwistle, 2008). Indeed, "*threshold concepts lead not only to transformed thought but to a transfiguration of identity and adoption of an extended discourse*" (Meyer and Land, 2005, p. 375). This transformative power of TCs resonates with David Hawkins' "critical barriers" to learning (Hawkins, 1978) which "*provide keys to the comprehension of a range of phenomena. To surmount a critical barrier is not merely to overcome one obstacle but to open up new pathways to scientific understanding*" (Hills & McAndrews, 1987, p. 426). Authors address relationships between TCs and similar ideas such as core, key and basic concepts (Cousin, 2008), and some take their metaphors a long way: "*A key is not the foundation that a building is constructed upon; it is what you use to open the door. 'Core concepts' are the building blocks, fundamental for building a discourse or syllabus, and the 'key' concepts, in our sense, make it possible to enter the building*" (Carstensen and Bernhard, 2008, p. 153). Meyer and Land (2003) make it clear that core and threshold are not synonyms: "*a core concept is a conceptual 'building block' that progresses understanding of the subject; it has to be understood but it*

does not necessarily lead to a qualitatively different view of subject matter" (p. 415).

Acquisition of a TC is "probably irreversible" (Meyer and Land, 2006, p.7) because the TC "*cannot be unlearned and represents a new world-view*" (Lucas and Mladenovic, 2007, p. 238). Threshold concepts are also 'integrative' by revealing previously-hidden relationships within a discipline, and the learning of a TC is essentially bounded, "*possessing terminal frontiers, bordering with thresholds into new conceptual spaces*" (Meyer and Land, 2005, p. 374). Threshold concepts are "potentially (though not necessarily) troublesome" (Meyer and Land, 2006, p. 8), a complex feature which lies the heart of TC theory, along with their transformative power. David Perkins sees this attribute of TCs as taking several forms, notably troublesome knowledge which is: inert; ritual; conceptually difficult; alien; tacit; or linked to troublesome language (Perkins, 2006, 2007).

STRAND 3: SELF-DETERMINATION THEORY

Finally, self-determination theory (SDT) (Deci and Ryan, 1985; Deci et al., 1991) is constructed around three basic psychological needs of (i) autonomy, (ii) competence and (iii) social relatedness. This is a complex theory of motivation so it relates very closely to interest, and SDT authors have contributed to the interest literature of the past decade (e.g., Deci, 1998). SDT addresses the reasons why certain outcomes are deemed to be desirable by the learner, compared with many other theories of motivation which emphasise the causal relationship between desired outcomes and the activity perceived necessary to achieve those outcomes. These purposes are expressed as three fundamental (and innate) psychological needs which all learners possess and which, by implication, should be fostered by teachers. The claims for these needs are ambitious (Deci and Ryan, 2000): "*innate psychological needs for competence, relatedness, and autonomy concern the deep structure of the human psyche, for they refer to innate and life-span tendencies toward achieving effectiveness, connectedness, and coherence. The presence versus absence of environmental conditions that allow satisfaction of these basic needs—in people's immediate situations and in their developmental histories—is thus a key predictor of whether or not people will display vitality and mental health*" (p. 229). Furthermore, the three needs are claimed to be "universal and thus must be satisfied in all cultures for people to be optimally healthy" (p. 246). Clearly SDT has practical implications for the world's teachers, parents, health professionals and many others.

Deci and Ryan (2000) have shown that intrinsic and extrinsic motivation are closely related within the learner's mind and that extrinsic motivation can be internalised by the learners so that it appears to emanate from the learner rather than the (external) teacher, as initially. Extrinsic motivation which becomes internalised and transformed into intrinsic motivation can lead to self-determined (*i.e.*, self-regulated) responses, leading to increased learner autonomy, the first of the three basic psychological needs. Indeed, the idea of 'autonomy' has long been related to intrinsic motivation: learning is better when learners experience intrinsic motivation (Deci and Ryan, 1985). Feelings of ownership (of tasks, timings, outcomes, products etc.) and autonomy have been shown to enhance motivation and learning. Ryan and Deci (2000) note that intrinsic motivation is undermined by the use of tangible rewards for task performance and that "*also threats, deadlines, directives and competition pressure diminish intrinsic motivation because ... people experience them as controllers of their behaviour. On the other hand, choice and the opportunity for self-direction appear to enhance intrinsic motivation, as they afford a greater sense of autonomy*" (p. 59).

The second need within the SDT model is 'competence': feelings that a task can be successfully undertaken and completed. Much empirical research shows that ideal learning activities provide optimal challenge. Put very simply, "*if it is too easy it tends to be boring and if it is too difficult it tends to be overly anxiety provoking*" (Deci et al., 1996, p. 176). Furthermore, positive feedback from the teacher strengthens intrinsic motivation and perceived competence, but only if (i) the feedback doesn't eclipse feelings of autonomy and (ii) the learner feels directly and personally responsible for the competent performance. In contrast, negative feedback undermines feelings of autonomy and competence and reduces intrinsic motivation (Deci and Ryan, 2000).

Finally, SDT posits a third basic need: 'relatedness'. This emphasises the social contexts of learning, involving teacher and peers, as well as the perceived relevance or purposes of the new learning. Although relatedness *per se* is deemed to be rather less influential on intrinsic motivation than are autonomy and competence, the relationship between autonomy and relatedness (ie social engagement) provides a dynamic tension which the teacher needs to resolve or accommodate.

GEOSCIENCE, DEEP TIME AND THE THREE STRANDS OF THEORY

Geological time ('deep time', see McPhee, 1981) is at the heart of geology (Albritton, 1963; Kitts, 1977) and provides a context for many topics within the geosciences, most notably environmental change (Gould, 1990), yet it remains conspicuous by its absence cross many school curricula (Trend, 2002). Conceptualisation of deep time has been addressed within educational research (Dodick and Orion, 2003; Hidalgo and Otero, 2004; Libarkin et al., 2007; Trend, 2001, 2002) but our understanding of its role in teaching and learning remains weak when compared with other pivotal concepts across the sciences, including the geosciences (Dal, 2007).

It appears likely that failure to develop a secure understanding of deep time can hinder both children's and teachers' further engagement with geoscience (Trend, 1998, 2001). In short, it is this lack of a deep time conceptual framework (or schema) (Trend, 2001) which leads to the proposition that deep time may be represented as a 'threshold concept' (Truscott et al., 2006), although the idea that some (high order) concepts per se can be seen to possess such 'threshold' or 'portal' characteristics is itself open to scrutiny (Rowbottom, 2007). Deep time conceptualisation may be examined in terms of wider conceptual change theory, *i.e.* beyond but including TC theory, and in relation to learners' interests, motivation and psychological needs: in short, the three strands identified above.

How might geoscience and deep time relate to our three bodies of theory? First, concerning interest, Trend (2005) reports that some "*children have high [individual] interest in major geo-events set in the geological past, present and future and in current environmental changes which have direct implications for the future of humanity. They also have coherent interest in gradual (i.e., uniformitarian) change in the geological past*" (p. 271). The sources of such interest were not investigated. For most people such robust individual interest needs to be nurtured through teaching, applying the four phases which promote progressive transition from "Phase 1: triggered situational interest", so easily generated over dinosaurs and drifting continents, through "Phase 2: maintained situational interest" and "Phase 3: emerging individual interest" to a mature "Phase 4: well-developed individual interest" (Hidi and Renninger, 2006). Geoscience teachers have many options for implementing this powerful model to enhance geoscience understanding (Trend, *in press*).

Combining the first and second of our three theory strands (interest and threshold concepts respectively), it is self-evident that student interest in geoscience threshold concepts, especially deep time, is likely to lead to secure geoscience knowledge and understanding which facilitates subsequent learning. It follows, therefore, that the 4-phase model of interest growth is best implemented through the deliberate designing of deep time-related activities which take the learner through those four successive stages. Thus, for example, Phase 1 might be manifest by the teacher showing an animation of Pangaea formation, with pupils predicting subsequent plate movements. Such pedagogical activities are common and routine, reflecting the omnipresent nature of situational interest. By Phase 4, however, less familiar activities on deep time learning might be initiated, such as students developing a school/college geology club in order to develop and publish (or display) a geological history of their local area.

Finally, we need to combine all three strands: interest, threshold concepts and self-determination theory. It is clear that the 3 cornerstones of SDT, autonomy, competence and relatedness, must be applied by teachers at all four 'interest phases' and across all geoscience threshold concepts. Such an approach will improve the quality of geoscience education and, in the case of deep time, will provide a temporal framework akin to a conceptual framework (Trend, 2001) for wider and more secure engagement with Earth history and its ongoing environmental changes.

Table 1 facilitates curriculum planning for deep time education, by giving planning pointers as well as types of evidence which indicate levels of student functioning in their geoscience learning.

Table 1. *Planning grid for learning with reference to interest, threshold concepts and self-determination theory: examples relating to the threshold concept of deep time.*

The four phases in developing interest (Hidi and Renninger, 2006, p. 114)	**Self-Determination Theory: three basic psychological needs (Deci et al., 1991)**		
	Autonomy	**Competence**	**Social relatedness**
Phase 1: Triggered Situational Interest (TSI) "a psychological state of interest that results from short-term changes in affective and cognitive processing" (p. 114)	Deep time example: Pangaea: origins, features, processes, evidence, timing, geoscientific implications.		
	Teacher gathers baseline data on student prior knowledge and understanding of Pangaea. Each student chooses one pair of adjacent continental areas for their individual study and selects between written and mapping tasks	Teacher ensures that written and mapping tasks are sufficiently open to permit access across the ability range. Deep time component has prominence in all resources. Much depends on teacher knowledge of students and their capacities	Students work in groups to produce a single product which combines the results of their individual studies
Phase 2: Maintained Situational Interest (MSI) "a psychological state of interest that is subsequent to a triggered state, involves focused attention and persistence over an extended episode in time" (p. 114)	Deep time example: teacher develops and teaches a unit in which students undertake research into the possible causes of dinosaur extinction, so students engage with changing global palaeogeographies and palaeoclimates		
	After engaging with the range of mass extinction theories, including their deep time locations, students select one for special study. Tasks specified in broad terms to allow further choice, within agreed limits.	Teacher advises and steers student choices so that they engage in activities at an appropriate level, ensuring deep time has prominence. Much depends on teacher knowledge of students and their capacities.	Working in a small group covering two mass extinction events, students present the evidence for and against their own events, emphasising similarities and differences between the two.
Phase 3: Emerging Individual Interest (EII) "a psychological state of interest as well as …. the beginning phases of a relatively enduring predisposition to seek repeated reengagement with particular classes of content over time" (p. 114)	Deep time example: the geological history of a region (*e.g.*, Transylvania, Carpathians)		
	Students carry out an individual study of one or more (consecutive) geological periods of their choice, negotiating with the teacher the geographical area and topics for special focus. Students choose to extend study beyond class.	Teacher ensures that student has sufficient knowledge, understanding and skills to undertake agreed study, eg relating to tectonics, palaeogeographies or palaeoecology: hence important of negotiation	Students expected (required?) to liaise with at least two other students concerning their chosen geographical area and/or one or more topics, in order to develop peer-support and collective development of expertise
Phase 4: Well-Developed Individual Interest (WDII) "the psychological state of interest as well as …. a relatively enduring predisposition to re-engage with particular classes of content over time" (p. 115)	Deep time example: school/college geology club/society established in order to develop and publish (or display) a geological history of the local area.		
	Once the geology society is established, students choose the nature of their own contributions. Minimal role for teacher	Tasks self-selected, so usually within the students' capacities. Teacher maintains advisory and steering role, typically sought by student.	Society committee organizes activities, with minimal advice from teacher.

CONCLUSIONS

It is concluded that effective teaching to foster secure, meaningful learning of pivotal (or 'threshold') concepts such as deep time may be achieved by: (i) providing support for learners which develops positive attitudes towards their own autonomy, competence and relatedness (ii) stimulating cognitive, emotional and intrinsic elements of interest (iii) including a curriculum designed deliberately to take individual learners through (four?) identifiable phases in the growth of their deep time interest, and (iv) allowing for transition between those stages through personal understanding which fosters internalisation of extrinsic motivation so that it appears to come from the learner and become, in effect, intrinsic motivation which stimulates greater self-regulation.

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