Handbook of Research on Driving STEM Learning With Educational Technologies

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Chapter 10
The Importance of the Disciplinary Perspective in Educational Research

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ABSTRACT

In addition to general findings from education research in the widest sense, further insights can be gained by considering the particular perspectives afforded from education within a specific discipline. In this chapter we present two such views: In part 1, we use the discipline of physics to highlight the distinctions between general and discipline-based education research and argue for a crucial bridging role for the latter. In part 2, we use the discipline of mathematics to explore the role of context while examining the use of mathematical modelling as a pedagogic practice.

INTRODUCTION

In addition to general findings from education research in the widest sense, further insights can be gained by considering the particular perspectives afforded from education within a specific discipline. In this chapter we present two such views. In part 1, the first author uses the discipline of physics to highlight the distinctions between general and discipline-based education research and argues for a crucial bridging role for the latter. In part 2, the second author uses the discipline of mathematics to explore the role of context while examining the use of mathematical modelling as a pedagogic practice.

PART 1: PARTICULAR CHARACTERISTICS OF RESEARCH ON EDUCATION IN SCIENCE AND MATHEMATICS

Research into education in the fields of science and mathematics at the Higher Education level can broadly be divided into two categories: what we might term fundamental or general education research

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(GER) and discipline-based education research (DBER). Generalising somewhat, the former largely takes place within Faculties of Education, mostly (although not exclusively) by researchers whose disciplinary expertise lies within education itself. In contrast, DBER is generally conducted by those with expertise grounded within the scientific and mathematics disciplines themselves. This may be an artefact of the comparative youth of DBER as a clearly identifiable disciplinary endeavour: for example, Physics Education Research (PER) originated as an identified activity only in the late 1970s. Henderson et al. (2012) found that the majority of active researchers in PER held PhDs in a traditional area of physics. However, that may be because opportunities for DBER PhDs have historically been scarce. This is less true at the current time: a number of institutions now grant PhDs in DBER, so in the future we might expect to find DBER more populated by those whose career path has largely concentrated on educational matters. However, it remains the case in the Americas, Australia and the United Kingdom that DBER is principally to be found within science departments rather than education departments. (The picture is less clear in continental Europe, partly because of a large degree of involvement of university science departments in the education and training of school science teachers, more so than is the case elsewhere; this has naturally led to a higher level of integration of activity between science and education departments. However, the general point stands.)

Research into teaching and learning conducted by Departments of Education often focuses on general principles of knowledge structure and cognition, methods of instruction, assessment techniques, etc. which are intended to be widely applicable across many disciplines. This research may be situated within or flavoured by specific disciplines (such as the sciences or mathematics) but is usually conducted with the methodologies and mindsets of general education. In contrast, Discipline-Based Educational Research is usually heavily contextualised within its own discipline, with a prime focus on applications and outcomes, rather than more general theoretical principles. Since, as discussed before, most DBER is conducted by researchers whose primary prior research experience was within their specific discipline, DBER is often strongly flavoured by the traditions and customs of the discipline, in terms of methodology and outlooks. (For example, Physics Education Research has traditionally prominently featured quantitative methodologies, as is consistent with the general approaches found in the field. Qualitative methods are often viewed with some trepidation - or even scepticism - by some practitioners, partially because those methods of investigation are very unfamiliar in the physical sciences. However, this too is changing as PER becomes a more mature field.) DBER studies are often strongly grounded within particular classes or courses, and revolve around attempts to improve the learning and attainment of particular cohorts of students; DBER studies, and those researchers who conduct them, are often highly operationally motivated.

In this article I will discuss some of the particular characteristics of DBER within science and mathematics, highlighting distinctions and commonalities with general education research where appropriate. I will argue that the strong disciplinary context and embeddedness of DBER is critical to its success, but will also highlight the importance of cooperation and collaboration between DBER and general education research.

Operational Application of DBER

As previously mentioned, the strong disciplinary contextualisation of DBER means that one of its main priorities is direct application of its findings to improved student attainment. It is therefore worthwhile to briefly review some of the principal positions it has adopted. As the present author is a physicist, I shall focus on physics, but the general principles are more widely applicable.

Much of the early work in PER directed its attention to conceptual understanding of physics ideas by students. Levels of student understanding can be probed using diagnostic tests (e.g., Hestenes, Wells and Swackhamer, 1992), and it rapidly became apparent that many students held strongly ingrained beliefs that were inconsistent with a correct physical model of the universe. Furthermore, the traditional instructional approaches widely used in university teaching (e.g. lectures) appeared to be largely ineffective in altering those student beliefs in any substantial way (McDermott, 1991).

Much of the subsequent investigation in PER consisted of experimental studies or action research that attempted to explore and evaluate alternative instructional approaches. As well as tackling conceptual understanding, these also addressed problem solving (both specific and generic), use of mathematics, and experimental and laboratory skills. These investigations relied critically on the disciplinary expertise of the researchers: as well as an understanding of education, they could employ their pedagogical content knowledge to attempt to understand why students had difficulty with particular topics, and develop possible solutions. Being embedded within the culture of the discipline allowed the researchers to be active participants in the teaching as well as the research, an option not available to those whose background is exclusively in education.

A large proportion of the findings could be described as a movement away from a ‘transmissionist’ approach to learning, which effectively models knowledge and understanding as artefacts possessed by experts and which can be transferred to novices. In place of these, a greater emphasis was placed on approaches which are consistent with a ‘constructivist’ philosophy. This position holds that each individual learner must assemble a structure of knowledge in their own mind. Pre-digested knowledge structures cannot be transferred from the expert; the expert instructor’s job is to assist the learner to build their own understanding.

The majority of the developed approaches could be broadly gathered together under the umbrella term of ‘active learning’. The active learning movement places emphasis on what students are doing during classes: in a traditional lecture, student behaviour is largely passive - listening, reading, watching, writing notes. The constructivist position argues that these behaviours are not conducive to the construction of knowledge networks in the mind. In an active learning classroom, students behave in a much more participatory manner: considering, deciding, answering questions, discussing, challenging and defending ideas. We should draw a careful distinction between the notion of ‘engagement’, in which students are interested and attentive, and active learning: the former can be achieved by some instructors in traditional ‘passive’ lectures, but this still does not feature the active knowledge construction that characterises active learning. Probably the most prominent example of active learning pedagogy in the physical sciences is Peer Instruction (Mazur, 1997), but many other examples also exist. Promotion of active learning now has a prominent position in reformed teaching and learning in science and mathematics. Numerous recent studies have established its value in an overwhelming range of disciplines and contexts, of which the most prominent is probably that of Freeman et al. (2014), the title of which - “Active learning increases student performance in science, engineering, and mathematics” - encapsulates the headline outcome.

These ideas were not new in general education - indeed, Dewey was writing about notions which are clearly identifiable as active learning in 1897. It is therefore unfortunate that it took so long for these ideas to be rediscovered by science disciplinary experts and applied in the classroom.

Outcomes of the Application of DBER

Given the compelling - some might say unambiguous - findings from discipline-based education research, we might expect that the reformed instructional methods developed by DBER would be widely adopted in mainstream science and mathematics teaching. It is therefore instructive to consider the extent to which this is indeed the case.

Dancy and Henderson (2010) write: "Gone are the days of "I tried this in my classroom and it seemed to work." Curriculum development is now frequently based on extensive teaching/learning theory along with rigorous testing and evaluation."

In an extensive, rigorous and highly representative survey of physics instructors in the United States of America, they found that 87% of instructors were familiar with at least one evidence-based, reformed instructional approach, and that 48% of instructors actually employed them in their own teaching.

In a similar study in the United Kingdom, Hardy et al. (2014) found that 64% of physics faculty knew of reformed pedagogies, and 27% actually made use of them in the classroom. These lower figures for awareness and adoption of evidence-based approaches, as compared to the situation in the U.S., is probably reflective of the fact that DBER is a younger, less mature and less well-resourced field in the U.K. than in the U.S., lagging North America by at least a decade.

On the face of it, these statistics for adoption of findings from DBER appear to be encouraging. However, they must be treated with some caution. Henderson, Dancy and Niewiadomska-Bugaj (2012) went on to discover that, of those faculty who adopted an evidence-based, reformed teaching approach, at least one third subsequently abandoned the use of the pedagogy. Hardy et al. (2014) found lower (but not negligible) levels of discontinuation in the U.K. (though this too, ironically, could perhaps be attributed to the younger status of the field in the U.K.).

This adoption and then abandonment of reformed practices is not restricted to physics. Andrews et al. (2014) conducted an extensive study of the teaching of biology and the life sciences in the United States. They reviewed a wide range of publications reporting on the effectiveness of revised teaching practices across a range of institutions and courses, and in their analysis found that - in stark contrast to the previous trend in DBER - the use of active learning approaches in biology were not associated with measurably different levels of student attainment.

When pressed for reasons for their subsequent discontinuation of evidence-based, reformed instructional practices, faculty offered a wide variety of reasons, but a strongly emerging theme could be summarised thusly:

I tried that – it didn't work.

Given the clear picture that seemed to be emanating from DBER, how then do we interpret this situation?

Translating DBER to Practice

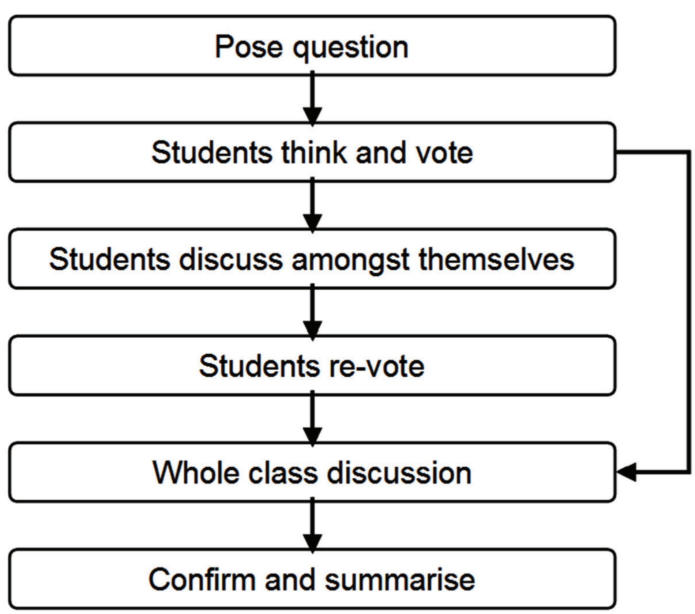
Further investigation into the nature of the classroom application of DBER findings may hold a partial answer. Henderson and Dancy (2009) observed that while a large fraction of instructors self-reported using particular, identified reformed pedagogies, when considering their actual classroom practices it was seen that between one quarter and one half of instructors deviated substantially from the pedagogic approach described in the literature and to which the DBER findings applied. The instructors might say that they were following a particular evidence-based teaching approach (and they likely genuinely believed that they did), but the activities occurring in the classroom might be markedly different to another instructor's interpretation of the same pedagogy.

For example, Turpen and Finkelstein (2009) examined a number of implementations of the Peer Instruction methodology in the classrooms of a number of instructors of varying levels of experience. While all the instructors stated that they used Peer Instruction, Turpen and Finkelstein found that it was rare for an instructor to follow the complete Peer Instruction cycle, as summarised in Figure 1.

Instructors routinely omit elements of the Peer Instruction cycle: for example, before the students discuss the question, it is recommended that the instructor hold a pre-vote, after the students have considered the problem by themselves. It is common for instructors not to take a pre-vote (usually the stated reason for this is to save time), and instead present a question and immediately ask the students to discuss it. A naive interpretation of constructivism would suggest that this is compatible with the goals of the session; after all, is it not the act of discussing ideas and hearing alternative viewpoints that is the educationally valuable element?

However, identifying the answer individually, and - crucially - committing to that answer by voting for it, is a very important element of the process. If this stage is omitted, many students will simply wait for a more dominant neighbour to volunteer their views and then uncritically adopt their answer. Even more importantly, committing to an answer before discussion forces students to adopt a clear position in their minds; if during the subsequent discussion, another student makes a strongly argued case for an alternative view, the student will experience cognitive conflict. The desire to resolve this conflict is strong, and it is the act of deconstructing previous, inconsistent viewpoints and incorporating the new position into the student's mental model that is the most educationally valuable. This is the heart of the

Figure 1. Sequence of classroom activities for a single Peer Instruction episode



constructivist process that Peer Instruction seeks to encourage, and so removing it from the cycle can fatally undermine the effectiveness of the technique.

The role of cognitive conflict in constructivist learning is well known in general education research, but if DBER practitioners or instructors who subsequently adopt the methodologies are too divorced from the underlying principles in operation then they can inadvertently modify the classroom techniques away from the established effective model, removing important elements because they do not know or understand why they are so important.

Similarly, after the second round of voting, if a large fraction of the class have responded with the correct answer, many instructors simply move on to the next topic, assuming that the class has 'got it'. This omits the closing stages of the Peer Instruction cycle: surfacing student reasoning via a whole-class discussion, and the instructor then clearly confirming and explaining not just the correct answer but the appropriate reasoning that leads to it. As Wood et al. (2014) discuss, Peer Instruction is a much more subtle process than simply 'students learn the correct answer'. The in-class Peer Instruction episode often acts mainly as framing for a learning process that extends over a longer period of time, spurring a process of assimilation and consolidation that takes longer than the few minutes available in the classroom. Many students might vote for a correct answer, but on shaky or flawed grounds, by luck, or by correct but poorly articulated reasoning. A clear closing statement from the instructor is therefore important to reinforce the correct answer and lay down secure foundations for the subsequent assembly of ideas that the students must do themselves.

As a pedagogy, Peer Instruction provides perhaps the most striking example of widespread variation in what is ostensibly uniform classroom practice, possibly because it has both a very clearly stated intended structure (Mazur, 1997) and also very widespread uptake in reformed physics classes, giving many examples of implementation. However, similar phenomena also extend to other classroom practices, for example the approach generically known as 'Cooperative group problem solving' (Heller & Heller, 1999).

Cooperative group problem solving is also a well-structured, well-defined classroom practice, and uses a five-stage problem solving process, sometimes called the 'Minnesota Model'. Loosely, the five stages can be described as: Focusing on the problem, in which the known conditions of the problem are examined and the desired goal identified; Describing the physics, in which the relevant physics principles are identified and their suitable application considered; Planning, where a route through the solution is devised; Execution, where the plan is actually carried out, making use of the parameters and principles previously examined; and Evaluation, where the obtained solution is considered to see if it satisfies the goal and if it withstands checks of its plausibility and likely correctness.

Cooperative group problem solving as a classroom approach has spread widely beyond its institution of origin and has been found to be an effective pedagogy (Heller and Heller, 1999). However, of the 96 instructors surveyed by Henderson and Dancy (2009) who made use of this approach, only 8.3% reported implementing it "basically as described by the developer". The plurality of respondents (47.9%) "used some of the ideas, but made significant modifications". Similarly to the situation found for Peer Instruction, many users omitted one or more of the five elements of the Minnesota Model. Less than one fifth of the respondents reported using four or more of the five recommended components, and levels of adherence to the described structure were highly variable between institutions.

These observations are consistent with the findings of Andrews et al. (2014) in their study of reformed teaching practices in the life sciences. They give a number of examples of how specific details of the implementation of active learning tasks may fail to incorporate critical elements of the pedagogy: for example, attempts to improve students' conceptual understanding may not explicitly address previously held misconceptions. If these misconceptions are not critically examined and found to be inadequate by the students themselves, they are unlikely to be discarded and replaced with alternate mental models. Additionally, in-class questions may be ineffective in promoting improved conceptual understanding if they merely require factual recall rather than triggering higher order cognitive processes. Andrews et al. (2014) state:

We contend that most instructors lack the rich and nuanced understanding of teaching and learning that science education researchers have developed. Therefore, active learning as designed and implemented by typical college biology instructors may superficially resemble active learning used by education researchers, but lacks the constructivist elements necessary for improving learning.

Thus we see the importance of maintaining strong links between the various elements of a successful reformed teaching approach: pedagogical content knowledge, discipline-specific educational research, and general education research.

CONCLUSION

We have considered the important role that discipline-based education research can play in the teaching and learning of science and mathematics. Researchers operating within DBER are uniquely placed to bring to bear their deep familiarity with the subject, allied to their pedagogical content knowledge, in order to play an integrated role: developing reformed instructional practices, actually implementing these practices as classroom instructors, and rigorously evaluating their effectiveness.

As specialists within their disciplines, they are comfortable employing the techniques and analysis methodologies of their own subjects: within science and mathematics, this often means that they are particularly skilled in statistical analysis and other quantitative methods. However, this does not mean that qualitative methods should be neglected, as these frequently provide insight of a different nature, as well as providing useful triangulation for the findings from quantitative studies. Crucially, they also 'speak the same language' as their colleagues within the same discipline: they understand and employ the specialist terminology of the subject, and tend to be less prone to the use of educational jargon which can be alienating to instructors. Accordingly, DBER researchers have an important role to play in translating educational research into a form that is accessible for disciplinary faculty.

However, we have also seen the dangers inherent in too great a separation between DBER and general education research. While there is a very important role for specialist education research within science and mathematics, we should guard against it becoming too separated from the wider fields of research into cognition, educational psychology, and general pedagogy. There are important insights to be had from these fields which illuminate and support the specific findings from DBER. Failure to take them on board can lead to the neglect of critical but perhaps underappreciated elements of reformed instructional approaches: this can in turn result in underwhelming performance in the classroom, which clouds or even undermines the findings from DBER. It would be unfortunate indeed if DBER established well-evidenced, comprehensively-supported reformed practices that nevertheless did not gain widespread traction because of the failure to effectively translate them into practice in the typical college or university classroom.

The challenge then is this: we must build effective partnerships between general education researchers, disciplinary educational researchers, and faculty instructors. We must find a common language and common set of touchstones so that communication is effective and research questions, methodologies and findings can be shared. Researchers must involve instructors at a fundamental level, so that instructors can internalise the principles behind pedagogic approaches and so apply them effectively. Equally, instructors must be able to communicate their experiences and perspectives to researchers so that they can obtain a realistic and nuanced picture of the challenges that face students and what actually goes on in the classroom. Science and mathematics education researchers have a central and important role to play, acting as the keystone in the process. Are they speaking to the right people, speaking in the right language, listening to the responses, and acting on them? When the answers to these questions are yes, effective partnerships will be formed, and the development of education research and its subsequent implementation in the classroom will be greatly strengthened.

PART 2: MATHEMATICAL MODELLING AND THE ROLE OF CONTEXT IN MATHEMATICS LEARNING

In education research there is a lot of controversy about the importance of 'context' in the process of learning. This controversy is best situated within the topic of 'transfer of learning', which has been for a long time central to education. 'Transfer' is, simply put, the process by which an individual uses knowledge or skills acquired in one context (e.g. classroom) to solve a 'similar' problem in a different context (e.g. at work).

In mathematics education, the metaphor of 'transfer' has given rise to the kind of utilitarian ideas that mathematics is a sort of toolkit that individuals use (largely unproblematic) to solve different problems. For example, Noyes (2007, p.35) cites a novice teacher (Sarah) saying: "It is perfectly reasonable to view mathematics as a toolkit, a bag of rules, methods and conventions that we can use to model, interpret or change the world around us".

The controversy about 'context' is if it helps or hinders the process of 'transfer'. Some researchers say that context takes mathematics nearer to the individual's experience and makes it understandable rather than meaningless (Boaler 1993a, Boaler 1993b, Sierpinska 1995). Boaler (1993b) explains that what happens in contextual problems is that students interact with the context of a task in many different and unexpected ways, and this interaction is, by nature, individual: students are constructing their own meaning in different situations. Then, students will transfer from one task to another, even when the external cues are different, when they have developed an understanding of the underlying processes which link the problem requirements and their significance in relation to each other.

Another view, coming from cognitive perspectives, claims that context actually hinders the process of transfer. Kaminski, Sloutsky and Heckler (2008, p.455), in their highly cited Science article, conclude:

If a goal of teaching mathematics is to produce knowledge that students can apply to multiple situations, then presenting mathematical concepts through generic instantiations, such as traditional symbolic notation, may be more effective than a series of "good examples".

In addition to this, some might argue that one of the main characteristics that makes mathematics 'powerful' is its abstract nature: by ignoring the unnecessary or superfluous details of a problem (i.e.

the context) one can produce abstractions that can be used in other situations that have the same inherent mathematical structure.

However, for some time now, many scholars have questioned the use of the metaphor of ‘transfer’ to describe what happens in learning. Some researchers say that transfer is impossible because all learning is situation-specific, context-bounded (Lave and Wenger, 1991). Others have called for the use of alternative, more illuminating metaphors (Beach 2003, Hager and Hodkinson 2009). This has been motivated by the considerable evidence against the fact that, in our educational systems, the process of ‘transfer’ seems to be rare, that is, it does not happen as often or as easy as we would have expected. For example, Haskell (2001, p. xiii) says:

Despite the importance of transfer of learning, research findings over the past nine decades clearly show that as individuals, and as educational institutions, we have failed to achieve transfer of learning at any significant level.

In view of the above, I will now consider some of the research that has sought to abandon the metaphor of ‘transfer’ to try to explain learning from a socio-cultural viewpoint.

Socio-Cultural Perspectives on Transfer of Learning and the Role of Context

Taking a situated perspective, Ozmantar and Monaghan (2008) describe a contextual view of (mathematical) abstraction, that is, they see abstraction as always situated. This view is in stark contrast to more ‘traditional’ views where abstraction is a process of ignoring the context in order to be able to generalise from the problem at hand. They cite Cole (1996, p. 135) as saying:

The boundaries between ‘task and its context’ are not clear-cut and static but ambiguous and dynamic… that which is taken as object and that which is taken as that-which-surrounds-the-object are constituted by the very act of naming them.

Some of their conclusions advance our understanding of the role of the context in the process of abstraction (and mathematical learning in general). In summary, they claim that: (1) The concrete and the abstract form a dialectical relationship as opposed to a linear one, i.e. development is a to and fro between the context and the abstractions; (2) Abstraction is a process of making sense of a concrete situation by discovering new meanings to establish interconnections amongst different elements of the whole (Noss and Hoyles 1996, van Oers 2001); (3) The consolidation of an abstraction is a long-term process in which an abstraction becomes so familiar that it is available to the student in a flexible manner. Every abstraction remains weak and inflexible if it is not consolidated; and, (4) Tasks that create opportunities for learners to discuss mathematical aspects of the construction are important in consolidating it.

What is important from Ozmantar and Monaghan’s study for our present discussion is that they see context as playing a significant role in mathematical learning, even in the process of abstraction which is considered by many the upmost mathematical activity. However, their view of a (abstract) construct being consolidated and ‘flexible’ enough to be used in other situations still resonates with the old view of ‘transfer’. From this perspective, knowledge is what is mobilised from context to context, albeit it has to be recontextualised (by the person) in order to be useful.

A more comprehensive view of the situation is given by Activity Theory perspectives. For example, Beach (1999) claims that ‘transfer’ defines a narrow and isolated aspect of learning. He proposes to use instead the concept of ‘consequential transition’. In this metaphor, Beach (1999, p. 113) emphasises:

(…) the centrality of symbols, technologies and texts, or systems of artifacts, in creating continuities and transformations through social situations. The processes of generalization and systems of artifacts weave together changing individuals and social organizations in such a way that the person experiences becoming someone or something new, similar to Dewey’s (1916) notion of development as “becoming”. Thus, the experiences of continuity and transformation are important to, reflected on, and struggled with by individuals participating in multiple social activities (…). Insofar as many of these experiences are life transforming, they have a developmental nature to them along with some notion of telos or progress.

Hence, what Beach is saying is that every transition involves a social change of the individual, a consequence (progress) to his/her self by the negotiation of the new context in which they participate. Notice that here ‘context’ is used in a much broader sense than that of a context in a mathematics textbook problem; here context refers to the socio-cultural context in which activity (e.g. a mathematics classroom, a pedagogical task) takes place. What is ‘transferred’ from context to context is not packages of knowledge and skills that remain intact, like the toolkit of a (mathematician) handyman; the process involves active interpreting, connecting, reflecting, struggling and reconstructing that is done in the social situation in which the individual participates. This has a wider consequence to just the knowledge or skills involved in this process; it is not only knowledge or skills that are shifted from context to context, it is the whole person.

Engeström (1987) developed a third generation of Cultural-Historical Activity Theory (CHAT)[1] to explain the complexity of (social) factors mediating human activity. Activity systems are the indivisible unit of analysis; subjects engage in this object-oriented activity with the purpose of obtaining an outcome (e.g. learn something, solve a problem). The community, the rules and the division of labour represent the social/collective elements of the activity, which interact between them and along with the tools mediate the activity.

Hence, when individuals transition from a context to another, from an activity system to another activity system, they bring with them their whole self, including knowledge and skills but also their dispositions, emotions, ways of understanding and facing situations, et cetera (their ‘habitus’ according to Bourdieu (1980). And they transition into a context where communities have their own specific, historically developed rules and division of labour, mediated by the tools available at that moment. The person then, in order to participate in that new context/activity, has to engage in a dialectic process of negotiation with the context, resulting in a change in both the person itself and the context.

So, for example, when engineering students engage in solving a mathematical problem they bring with them their engineering identities, including the rules and tools acquired in their undergraduate engineering communities. They then will have to negotiate the rules, the tools and the division of labour that this new activity poses: it might be that students will use a computer software (tool) to plot a graph because that is what the module or the teacher specifies (rules of the classroom community), trying to make sense of how the output (graph in the computer) relates to the problem itself. Furthermore, if they are trying to solve the problem within a group, they have to follow the particular rules and the division of labour of that group. Hence, for example, students might take roles within the group and might have to discuss their ideas to get to a solution. This complex process brings a sense of development in the student (they are now able to do something they couldn't do before), a consequential transition where the person and the context change (students might feel they are now closer to become 'real' engineers, and the problems they face are now closer to what 'real' engineers do).

CHAT perspectives posit that consequential transitions take place through the interaction between activity systems (boundary crossing) where both systems learn from each other by creating boundary objects (Akkerman and Bakker 2011). These authors identify four fundamental mechanisms that take place at the boundaries of activity systems: identification, coordination, reflection and transformation. So, in the example of engineering students learning mathematics, it is not only mathematics that is used in and influence engineering, but it is also engineering affecting the learning of mathematics and the kind of mathematics that is learnt. The tools developed in such ways (boundary objects) can show how mathematics applies to engineering but, crucially also, how the engineering context influence mathematical work. This action and interaction works as a resource for the development of intersecting identities and practices. For example, in a recent case study (Hernandez-Martinez 2013) about two undergraduate students (one an engineering student and one a mathematics student) working together, I showed how they were able to establish a genuine collaborative dialogue (in a Third Space) through a mixture of conflict, challenge and responsibility to achieve the goal of creating modelling activities; the results were that:

The type of hybrid learning that resulted from engaging in this Third Space seemed worth the effort. For example, it was seen that Ron constantly uses graphs and is able to express things concisely (through abstraction) while Jack is not used at combining things together, perhaps because for him this makes things "more interesting". However, these different discourses and positions (i.e. the way you are as a mathematician as opposed to the way I am as an engineer, or vice versa, and the things we do differently) were negotiated and as a result new, hybrid understandings and ways of being emerged. (p.12)

Finally, Wenger (1998) introduces the concept of a broker to describe someone that is able to make new connections across communities and activities, facilitating coordination and opening possibilities for new meanings.

I will now examine how mathematical modelling, as a pedagogical practice, can be characterised from the perspective of transitions and boundary crossing, and how context is fundamental to the learning of mathematics.

Mathematical Modelling as a Contextual Pedagogical Practice

Mathematical modelling has been extensively studied and reported in the research literature. However, there is still debate about its definition and the aims that modelling should have in mathematics learning. Kaiser and Sriraman (2006) describe the different perspectives that researchers have in relation to mathematical modelling. For the purpose of this paper, we briefly analyse the "contextual" perspective, which aims to align more closely to the socio-cultural framework than was described in the previous section.

Within this perspective, Sriraman and Lesh (2006) state that modelling is about: (1) purposeful description, explanation or conceptualisation of a problem, i.e. mathematisation; and (2) designing and making sense of complex system that occur in real life situations. In the classroom, teachers should use "modelling-elicit" activities to enable students to develop models to make sense of specific situations, and these models should be powerful, sharable and re-usable.

What is important about this viewpoint is that the activity of modelling always happens in a specific "real life" situation, a problem-in-context; then, modelling is aimed at making sense of that problem by developing and using mathematical models. These models, as Sriraman and Lesh say, should be powerful (so as to accurately describe the situation), sharable (in order to convey to others meanings and explanations about the situation) and re-usable (to be used in other, different situations). From these characteristics, the re-usability seems to be the one that evokes "transferability". But, what is it about mathematical modelling that enables students to "re-use" their models in different contexts?

The key here is that the process of modelling is not only directed at making sense of a situation but it has an implicit purpose of developing models that can be useful, re-usable somewhere else. And even though students develop these models in specific contexts – which give meaning to the process –, there is a longer term goal: students must imagine how these models can be used elsewhere. Wenger (n.d.) describes the notion of imagination as:

As we engage with the world we are also constructing an image of the world that helps us understand how we belong or not. If you work as a social worker in a given city, you know that there are countless other social workers in other contexts and you can use your imagination to create a picture of all these social workers and see yourself as one of them. We use such images of the world to locate and orient ourselves, to see ourselves from a different perspective, to reflect on our situation, and to explore new possibilities. The world provides us with many tools of imagination (e.g., language, stories, maps, visits, pictures, TV shows, role models, etc.). These images are essential to our interpretation of our participation in the social world. Imagination can create relations of identification that are as significant as those derived from engagement.

Therefore, as we imagine how our mathematical models can be used in other contexts we create "relations of identification" or connections that serve us to transit to new contexts. As said before, this boundary crossing implies not only knowledge and skills but the entire self; imagination is intrinsically related to our identities as we cross from activity to activity, from context to context.

I will illustrate this with a case study of second year undergraduate engineering students in a mathematics module. This module was designed with the aim of developing in students useful employability skills (e.g. problem solving, effective communication, group work), and mathematical modelling activities were extensively used for this purpose. The idea was that students would engage in these activities because they perceive them as relevant to their present studies (the context of the problems) and to their future as professionals (see Hernandez-Martinez and Goos 2014, for a full description of this case study).

At the end of the module, a sample of students were interviewed about their experiences and their learning. A common theme amongst the interviewed students was the connection that they made between modelling, their identity as engineers and an imagined future. For example, Derek said:

Derek: *I think as an engineer is definitely useful and it also gives you experience you could use in other areas like real world modelling not just here… science or other fields that may interest you even though you are not doing it and in this module there was a lot of modelling and modelling cycle and stuff like that… good work.*

In this quote, it is clear how the student sees the relevance of modelling to his identity as an engineer, and how he can imagine using this learning, "even though you are not doing it", in other contexts.

Another student also talked about preparing for the future, and how he sees himself using what was learned in the module:

Alan: *I can see where he (the lecturer) came from with obviously wanting to develop people's kind of just, you know, individuals and you know, preparing people for later life and not necessarily just for exams because obviously university is only four years of your life and you've got to go into do the real world stuff and it's not all exams there and you should be able to speak to people and you know, do group presentations and stuff like that so is probably quite useful to do those kind of exercises.*

In this case, Alan is able to see how the "kind of exercises" encountered in this module are useful to prepare him "for later life", and how developing skills such as effective communication or doing group presentations are relevant for him while he prepares for the world of work. Obviously, school and university are not the same as professional work but here is where the use of someone's imagination can make the necessary connections to what one imagines it will be to become a professional and to do what professionals do.

CONCLUSION

In this chapter, I have explored the role of context in mathematics learning through the lens of socio-cultural theories and the pedagogical practice of mathematical modelling. Within these perspectives, context refers to something greater than just a "background" from a textbook word problem. It entails a whole social structure in which individuals participate every time they engage in object-oriented activity.

This context, with its community, rules, tools and division of labour is essential in making meaning of situations and in enabling individuals to participate fully in social activity. In the case of mathematical modelling activities in the classroom, students engage in making meaning by creating models, or mathematising the situation. However, this context-bounded activity does not mean that individuals cannot cross boundaries and make their knowledge and skills useful in other contexts, with other set of rules, tools and division of labour. The key to successful transition, a consequential one, is the use of imagination in establishing connections to other contexts "even though you are not doing it". It is, to put it in Lerman's (2000, p. 26) terms: "Learning to 'transfer' mathematics across practices is the practice".

Therefore, there is an implication of this to teaching: Activities in the classroom should not focus on 'transmitting' knowledge, even worse if this is only to "pass the exam", but they should instead concentrate on enabling students to create boundary objects that will be useful in future situations. Students should be capable of imagining themselves using these objects in other contexts, in as many contexts as possible; they should be able to visualise themselves crossing boundaries, "becoming someone or something new" (Beach 1999, p.113).

OVERALL CONCLUSION

In this chapter we have considered two perspectives on teaching and learning. Through the lens of Physics, we have considered the interplay between general educational research and discipline-based educational research. From the field of Mathematics, we have examined the role of mathematical modelling in learning mathematics. In both cases, the distinctive characteristics and modes of practice of each discipline have been critically important, but some common themes are also evident: transfer, context and disciplinary identity.

In Part 1, a key consideration was the transfer of successful pedagogical innovations from the environment in which they were developed to the wider educational community. In Part 2, a motivation for the teaching of mathematical modelling was to promote transfer of the understanding of underlying mathematical structure from one application into a seemingly unrelated application. In both cases, context is vitally important: there is an interaction between process and context which is complex and intrinsic. Attempting to understand process in the absence of the context can lead to limited and flawed implementations that lack the essential elements needed for success, be it in the specifics of mathematical modelling or in the teaching and learning of science more generally.

Furthermore, in both cases the establishment of a clear disciplinary identity can be seen to be of benefit: in Part 2, identifying as disciplinary practitioners – mathematicians, engineers, etc. – allows students to more easily grasp the relevance of context and to imagine the utility of mathematical processes in the wider world. In Part 1, the situation of disciplinary based educational researchers within their own disciplinary identity allows them to employ a common language and familiar modes of thinking with their disciplinary peers, bridging the gap between general education and the specifics of science teaching: this enables them to facilitate the transfer of ideas and techniques successfully between contexts.

In summary, our examination of two aspects of the teaching and learning of science and mathematics from a disciplinary perspective has revealed important commonalities but has also highlighted the value and insight that a contextually situated view brings.

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ENDNOTE

[1] CHAT originated in the works of Vygotsky and was later expanded by Leont'ev, Luria and others.