The STEM Agenda in the Context of Initial Teacher Education: Challenges and Potential Ways Forward

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The STEM agenda within the UK 'is a series of initiatives geared towards creating a strong supply of scientists, engineers and technologists' (QCA, 2007). One curriculum strategy being tried is the fostering of links between STEM subjects. This paper explores the potential of such a strategy by researching a small scale curriculum initiative within a one year full time post graduate teacher education programme in England. CHAT analysis served to provide a theoretical lens showing how trainee teachers had to make difficult boundary crossings between the different demands of the university based and school based elements of training. The paper concludes that the STEM initiative needs to be proactive in reconciling the tensions that exist when boundary crossing occurs whilst also providing opportunities for establishing boundary zones for key players to operate in.

Introduction

The effectiveness of Science Technology Engineering and Mathematics (STEM) education is currently preoccupying educators at all levels in national education systems, both in post-industrial and newly-emerging economies. Boundaries between STEM subjects in school have been found to limit students' learning through the low transferability of knowledge between different cognitive contexts (Tuomi-Grohn and Engestrom, 2007). This paper extends this analysis to study the advantages perceived, and the difficulties faced by trainee teachers in STEM subjects in building and using effective links in pursuit of connected and integrated pedagogical practice. It utilises an activity theoretical analysis around boundary crossing in order to make sense of these perspectives in social and goal-oriented contexts.

The idea that subject-specific learning is less important and relevant to young people leaving school in the twenty-first century is one that has been gaining ground over the last decade in the UK. We associate the STEM discourse as part of a move towards 'dispositions not disciplines' as a pedagogical and curricular framework for schooling. An increasingly substantial body of literature highlights the relevance of an integrative learning disposition (Carr and Claxton, 2002) as a high-value, although easily-disrupted characteristic of young people's learning. Dispositions have been defined in various ways: a 'tendency to edit, select, adapt and respond to the environment in a recurrent, characteristic kind of way' (*ibid.* p.13), which captures the issue of the degrees of agency, habit and awareness with which a person responds to their environment. The argument is that education should now be aiming at 'facilitating the development of the capacity and the confidence to engage in lifelong learning' (*ibid.* p.9), and this involves promoting the development of dispositions such as 'resilience, playfulness and reciprocity' (*ibid.* p.9) rather than bodies of knowledge. Such dispositions may provide a helpful framework with which to examine the learning of teachers in response to the kind of changes in emphasis that these dispositions themselves require.

An educational emphasis on disposition remains contentious. It is argued, for example, that the assessment of learning dispositions remains highly problematic, with particular issues around their stability and therefore the fairness of using such judgments to categorise young people in the way that secondary schooling has typically operated (Sadler, 2002). Subject specialisation, concentration on content to the detriment of process skills, and a commonly-felt need by young people to create and maintain a coherent identity in relation to ability are all identified as possible threats to the promotion of dispositions.

STEM in the UK

In the English national context the STEM agenda is an attempt to coordinate the numerous initiatives in curriculum design of both individual STEM subjects and to bring together STEM-related initiatives and implement them more effectively in every school, college and learning environment. The overarching economic aim is to contribute to the UK's global competitiveness through a strong supply of scientists, engineers, technologists and mathematicians at technician level and above. At the same time the development of STEM literacy in the general population is also a key focus of the proposed developments.

The translation of such an agenda into practice is however an unclear one as the implications for changing the teaching of STEM subjects in schools have not yet been established. Despite the arguments in favour of a 'dispositions' rather than 'disciplines' approach, the reality within schools is still of strongly separated individual subjects with a stronger sense of boundary than of connection and overlap. There is as yet no clear sense of strategy for school practitioners associated with this agenda, or sense of the degree of structural reform that will be feasible and desirable within the curriculum and organisation of secondary schools.

It is however possible to identify a slowly emerging rationale as to the individual yet connected contribution of individual subjects to an interdisciplinary agenda. The contribution of Technology (Design and Technology) to the STEM agenda is concerned with the conception of what does not yet exist and how this may be brought into existence through the application of creative processes requiring normative knowledge. The position of technology within STEM has 'oscillated between insignificance to valued contributor' (Barlex, 2008). Whilst the subject remains a recent addition to the school curriculum, its contribution has remained difficult to assess. However with approximately 700 UK 'specialist schools' having a curriculum focus on engineering or technology education and the emergence of specialist diplomas, at age 16, in engineering and manufacturing from 2010 the subject's contribution to the STEM agenda could be a significant one.

Science education has historical and institutional connections in England and Wales which serves to reinforce a stable, if not conservative approach to practice in many schools. Science education is well-represented by the Association for Science Education which enjoys a relationship with a range of well-established national institutions representing various scientific disciplines such as the Institute of Physics, the Royal Society of Chemistry. In schools, these institutions sponsor the development of a host of initiatives designed to foster links between education and industry, and there is great potential for well-contextualised and stimulating curricular experiences that cross, for example, the boundaries between the many sub-disciplines of science and engineering. What remains in question is the readiness of school science departments to wholeheartedly embrace some of the more far-reaching curricular developments which forefront the STEM agenda, whilst highlighting the need for conceptual development and practical skills for a minority entering STEM-related careers.

The role that mathematics has to play in a STEM education is perhaps open to (mis-)interpretation, as highlighted by the Robert's Report (2002) which indicated in its title, "SET for success", a lack of understanding about its centrality which has since been corrected in principle if not in practice. This is perhaps indicative of the lack of immediate "utility" of current school mathematics: this is currently being questioned with mathematics education being repositioned to more adequately foreground an applications approach. Whilst this is partly in response to an increasing awareness of the role it needs to play in a STEM education, it is perhaps more pragmatically due to a reaction to league tables resulting from international studies, such as PISA (OECD, 2002), which have drawn attention to applications of mathematics, not only as providing preparation for work but also so that students might become better able to use mathematics as critically aware citizens.

What is apparent from this brief overview of disciplines is that there are distinctive but overlapping challenges in respect of each of these subject areas in promoting a significant shift towards the integrated development of STEM-related learning dispositions. One obvious possibility is to look to the new entrants to the profession as contributing to change in their respective secondary schools. It is within this context that the research study is located.

STEM in the Context of Initial Teacher Education

Initial teacher training (ITT) is subject to a degree of government control in England and Wales, which influences the regulation and assessment of potential teachers through a system of inspection and an agreed set of professional standards in which trainee teachers must demonstrate competence (TDA, 2007). Given this situation, ITT is regarded by some government agencies as a lever for change in schools, with newly-qualified teachers invited to see themselves as 'change agents' in influencing professional practice in their schools (*ibid.)*

Our experience in working with graduate trainees in the context of a one year post-graduate course preparing them as Secondary (11-18) teachers in the three STEM-related disciplines is that they are significantly influenced by the ethos of the schools in which they spend the required 120 days of their time. Nevertheless, a university course maintains capacity to frame this school experience through a variety of assessment and pedagogical tools, and through a range of curricular experiences within the university (Tsui and Law, 2007). As we report here, the aim was to identify trainee perceptions related to the opportunities and challenges of emerging STEM agenda for both themselves as teachers and for the students that they will teach. As we will see, a number of tensions emerged around trainees' reactions to the possibilities of cross-curricular links within the university course. To pick up on the learning dispositions highlighted by Carr & Claxton (2002) above, we explored whether trainees would demonstrate playfulness and reciprocity when faced with a cross-curricular learning experience, and whether the outcomes would demonstrate the value of such experience as part of the development of responsive and creative teachers.

Within this context, the authors instigated a small scale research and evaluation activity involving an innovative collaborative learning experience involving 140 science, maths and technology trainees. Trainees were asked to collaborate, over the course of a STEM day, in small inter-disciplinary groups to complete a series of tasks. Throughout the day the trainees were also invited to reflect before and afterwards on their perceptions of the similarities and differences between their subject disciplines, and on the subject-related dispositions that they brought to bear individually and jointly in addressing the challenges posed by the tasks. Methods employed in the research data collection included questionnaires (pre and post event), observation and follow-up focus group interview.

In preparation for the day trainees were asked to complete a task, which involved measuring the height of a building, in small groups based within their usual subject groups. They were then asked to reflect on the "height of buildings" task, as if they had used it with students aged 15 to 16, considering what would students learn from it? They were then asked to record the three most important learning outcomes of the activity.

During the STEM day, the initial activity for each cross-curricular group of four trainees was then to share and discuss their recorded learning outcomes and to rank them, as a group, from most to least important outcome. This was recorded in the form of a poster explaining their decisions. Groups were later asked to collaborate in the design and construction of a hanging mobile which would incorporate principles and features of all the contributory subjects. The completed mobiles were peer-assessed and the most highly-rated were then asked to present their products, prior to a plenary discussion.

This was the first occasion that these trainees and tutors had collaborated together in this way on the ITT course. The purpose of the research was therefore to explore how collaboration between teachers of these subjects might benefit learning in all three areas, and also to highlight some of the distinctive value of each subject in relation to the others. Evaluation of trainee feedback suggested firstly a considerable diversity of response, ranging (for example) between trainees who maintained a rigid personal and professional identity with their chosen subject area, to those who expressed excitement and enjoyment at the possibility of utilising connections between these subjects in their own school practice. One element contributing to this appeared to be the trainee teachers' conceptualisation of subjects within the curriculum, either as actively-related contributions to a 'big picture' or as self-contained disciplinary units (a distinction which reinvents the debate over the place of disciplines in the education of young people).

Playful Teachers?

Many trainees appeared to draw reassurance from the boundaries around their subject. Immediately after the event, we reflected on the way that some trainees had simply 'wanted to be told what to do and how to do it'. Nearly half of the 150 responses to the evaluative invitation to 'identify three things that you have learnt during the day' concerned the STEM agenda, or related changes to the curriculum. Most trainees mentioned a greater awareness of the new national curriculum which is being introduced from September 2008 as allowing more of a focus on process skills than subject content; one mentioned 'An awareness of an ill thought-through STEM agenda and that we may become responsible for taking forward STEM in the absence of a national strategy'. These responses seemed to reflect the value placed by many trainees on knowledge gained, and also a sense of trepidation in terms of possible future contributions to curricular innovation. As a consequence of this many trainees appeared to see themselves as vulnerable to the decisions of others in relation to curriculum development, whilst a relative minority relished the recognition of their own potential and active contribution to the STEM debate. For example, trainees identified twelve pedagogical ideas to inform their future teaching, and of these there were just a few that suggested an enthusiasm for encouraging the development of pupil dispositions such as creativity (e.g. 'encourage pupils to try different things' and 'clearly defined goals can be restricting').

It appeared that some trainees had difficulty in conceptualising how they, as new teachers, would contribute to developments that had not been fully trialed before implementation. We see the relationship here with the disposition of playfulness, as elaborated by Carr & Claxton (2002): "Often just 'messing about', without a clear goal or purpose, reveals new affordances and thus makes both new means and new goals possible. (What one might want to do emerges from an open-minded exploration of what one can do)" (p.15). We pondered the possibility that our invitation to playfulness in the activities of the day contradicted a dominant conventionality within the mode of ITT, with its reliance on lectures, competences and subject-specific organisation.

Reciprocity as a Teacher Disposition

In addition, there was a sense from some groups that they found it challenging to move beyond their newly-found identities as subject teachers, whilst others were buoyed by a sense of discovery and enjoyment at interacting with others who came from a different perspective from themselves. Again, it is helpful to link back to a disposition identified by Carr & Claxton (2002): "reciprocity will include a willingness to engage in joint learning tasks, to express uncertainties and ask questions, to take a variety of roles in joint learning enterprises and to take others' purposes and perspectives into account" (p.16). Another 36 responses in the evaluative questionnaire mentioned collaborative work, or aspects of the collaboration that the trainees had been engaged in during the day. 'Learnt how to work in a group' was typical of many; 'learnt how to communicate with a mathematician' was one of the more enigmatic. 'Always have a DT teacher in your "make a mobile" team' was the most direct comment on the value of cross-subject interaction. Another 33 responses detailed ways in which they hoped to take the experience of team working as an influence on their teaching: 'possible use of similar activities used inter-departmentally…' and 'teachers from different backgrounds can work together easily…'.

Perhaps most interesting were the minority of 24 responses which identified learning, either differences or similarities, between the subjects involved and the approaches taken by trainees in different subjects. For example, three responses mentioned learning about the similarity between maths and science (e.g. 'how scientists and mathematicians often think in the same way'), implicitly noting in this case something distinctive about design and technology. Other responses focused on differences (e.g. 'how different subjects prioritise learning objectives'), identifying the need to negotiate priorities when collaborating between these subjects. Still others highlighted the positive value of different perspectives (e.g. 'has enforced the view that other perspectives can be enlightening'). In addition there were twelve responses which mentioned, as features of the activity which would 'inform their future role', various dispositions, notably creativity, critical evaluation, and problem-solving. Again, this was a minority type of response, suggesting at the very least, the need to reconsider our pedagogical approach, and perhaps a need to consider the dominant messages from the hidden curriculum of ITT. More positively, these responses demonstrate that there are at least a proportion of trainees who are not unreceptive to the possibilities of cross-curricular linking.

Recording and analysis of conversations within collaborating groups offered a further useful complementary insight into the processes with which trainees engaged in the task, so that (for example) individuals employed analytical and synthetic thinking in very different ways that aligned with their specialisms. Findings also offer some tentative explanations for some of these differences. Therefore, it was mainly the trainees with prior industrial and other relevant experiences who were most enthusiastic about the process of boundary crossing between subjects, whilst those who had come more directly from school and university education were more constrained in their sense of possibility. The implications of the research include questioning the extent to which a course of ITT (and perhaps by extension, continuing professional development in this area) can and should shape the attitude of individual teachers towards their subject and its relationship with others.

Understanding the Boundaries

In an attempt to focus on the tensions, and indeed difficulties, which arose as the trainee teachers and their tutors attempted to consider what the STEM agenda might entail for them, and to shed light on what we might prioritise to facilitate moving forward, we drew upon Cultural Historical Activity Theory (CHAT) as a theoretical lens. CHAT is developed from the Vygotskian notion that activity is goal-directed and mediated by culturally developed "tools" (including artefacts, signs (in the sense of Peirce), language (Bakhtin et al., 1986)). Leont'ev (1978) extended the focus from that of the individual to the collective identifying rules, both formal (written) and informal, division of labour and community as important factors. Engeström's (1987) schema (Figure 1) represents this by shifting attention from where the top triangle focuses on the individual to subsequently include the other nodes.

A CHAT lens, therefore, ensures that we focus on the "collective" involved in ITT as well as individuals, who in real-

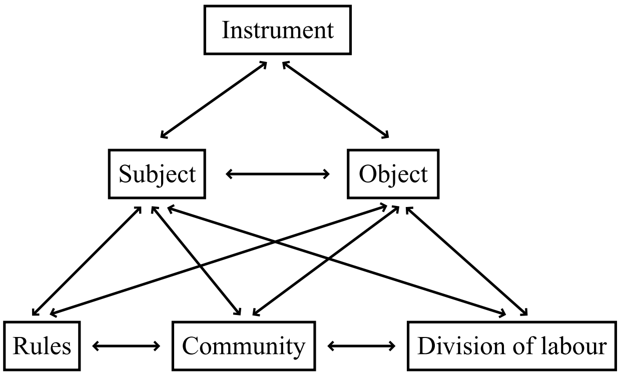

Fig. 1. Schema of Activity System

ity work and are held accountable in different and often inter-connected activity systems. ITT as it is currently constituted in the UK, in the model reported here, involves "partnerships" of Higher Education Institutions (HEIs) and local schools with the HEI being the lead and ultimately accountable partner. This results in trainees being actively engaged in two activity systems that in practice may have different objects: (i) the HEI where the object of activity is the education and ultimately qualification of the trainee teacher, and (ii) the school (in reality each trainee spends some time in at least two different schools) where the object of activity is the education and qualification of its pupils. As Edwards & Mutton (2007) point out these different objects of activity are problematic for the partnership model of ITT: they report that those in schools charged with the coordination of trainees face difficulties as they try to accommodate these responsibilities alongside their overriding need to work towards the goals of their schools, that is the education of young people. This is particularly problematic in the current climate of measurement and accountability where performance of pupils in high stakes assessment is aggregated to determine a school's position in local and national league tables. Somehow, therefore, trainees have to reconcile boundary-crossing between the two activity systems of HEI and school as they attempt to meet the objectives of each: that is, they must fulfil the HEI's requirements, that incorporate meeting nationally laid down 'Standards', leading to 'qualification to teach' whilst at the same time establishing a role in the school community which has as its prime concern the education of young people.

There are, however, important features of the two activity systems of school and HEI that are aligned and indeed may be thought to redefine each as collectives of horizontally (i.e. not hierarchical) interacting "departmental" communities based on subjects or disciplines. Each is structurally designed, particularly in terms of rules, division of labour and in terms of the artefacts it works with (defining curriculum, timetable and so on) based on, in the main, long established, school subjects. Each, therefore, foregrounds subject specialisms with trainees having from the point of application onwards to opt to study to teach a particular subject. This is a strong structural design feature of the ITT course with the majority of time being spent by trainees in subject specific groups: this is accentuated during the trainees' time in schools where they work almost entirely within a subject department under the guidance of a mentor drawn from the department's staff. Although a substantial proportion of trainees suggest that they chose to be a teacher first, prior to identifying the subject they would teach (reflecting the choice open, for example, to a science or engineering graduate) the communities into which ITT inducts them are strongly subject orientated and have culturally and historically evolved as such. It is perhaps not surprising, then, that trainees develop strongly subject-oriented identities.

We are, therefore, led to conceptualise the trainee as currently having to work in crossing boundaries between two activity systems, that of HEI and school, where in fact these might best be thought of as "subject departments" which are HEI and school-based. The HEI intervention, described here, therefore led to dissonance for the trainees as they were asked to think outside and across the usual well-bounded systems into which they had only recently been inducted. Discussion of such boundary crossing has led to the development of two concepts which are useful: boundary objects and boundary zones. Boundary objects are tools, often artefacts that have a role to play in each system: in terms of ITT the documentation that is used to inform and document the development of trainees is an example of such a boundary object having a role to play in both HEI and school. Edwards & Mutton (2007) highlight that this can be problematic as it often reflects the hierarchical positioning of each activity system with the flow of documentation *from* HEI *to* school. They suggest that "boundary zones" need to be developed in which key players from each activity system can work together to produce jointly appropriate instruments / tools (boundary objects) to assist boundary crossing. Such considerations, perhaps obviously, seem to apply to the intervention reported here. We asked trainee teachers to reconfigure their understanding of the activity systems in which they operate without equipping them with either the mediating tools (boundary objects) or the necessary space (boundary zone) in which to do so.

Our research of this small scale intervention reported here, we suggest, is useful in drawing attention to the problematic nature of the "top-down" imposition of a curriculum (re-)design such as the STEM agenda. It highlights the strength of the culturally and historically situated design of school and ITT structures which militate against ease of their redesign, and suggests that attention needs to be paid to all aspects that mediate the activity of the school and HEI communities if this is to stand any chance of success. Specifically, structural features such as the division of labour (often organised around subject departments), rules (such as timetabling) and tools (such as curriculum specification and assessment) require attention, *and importantly*, boundary zones in which these can be worked on by the community need to be established. Our work in ITT suggests that such interventions are required both in schools and HEI institutions responsible for ITT, as well as facilitating active partnerships where a STEM approach to the training of new teachers can be jointly developed.

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