Beyond the subject silos in STEM – the case for 'looking sideways' in the secondary school curriculum

Conference or Workshop Item

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Abstract
This paper considers how teachers of each of the school subjects science, mathematics and design & technology might adopt a positive approach to STEM by 'looking sideways' and taking into account in their own teaching what colleagues from each of the other subjects are teaching. The paper will use the invited comments of three distinguished educators, one from each of science, mathematics and design & technology for an initial exploration of what this might involve.
Then the paper considers two possible futures of STEM: the first in which teaching the subjects is independent one from another, the acronym to have a full stop between each of the letters as it were - S.T.E.M; the second in which there is a dynamic and synergic relationship between two or more of the contributing subjects. Each future is considered in the light of comments from teachers in Israel, Argentina and Brazil. Finally the paper discusses the idea of ‘looking sideways’ for the development of teacher professional knowledge.

Goals and objectives
The goal of this paper is to discuss two related features of STEM education in secondary schools.
The first is to establish the potential benefits of teaching one STEM school subject in ways that take into account what is or has been taught by colleagues teaching in other STEM subjects. To this approach we give the term ‘looking sideways’ in the curriculum.
The second is to consider two possible futures for STEM education in the light of comments from teachers in Israel, Argentina and Brazil.
For the purposes of this paper the STEM subjects considered are science, mathematics and design & technology (often named technology in countries other than England).

Theoretical framework
The theoretical framework is predicated on the centrality of teachers in a curriculum and any attempt to effect change in a curriculum.

> “Educational change depends on what teachers do and think – it’s as simple and complex as that.”
> Fullan and Stiegelbauer (1999 p.117)

This centrality of teachers is then considered in terms of the knowledge-creating school (Hargreaves 1998). Hence we use what some teachers and educators say about the relationship between the STEM subjects to build an understanding of the benefits of ‘looking sideways’ amongst the STEM subjects and indicate how this can be enacted in terms of the knowledge creating school.

Methodology
In response to our position with regard to teachers we have interviewed three distinguished educators, one from each of science, mathematics and design & technology and report on those interviews.
From design & technology we interviewed Torben Steeg in April 2011. Steeg is a freelance consultant in education, and is widely regarded as a national expert in the teaching of electronics, systems and control and modern manufacturing. He also has a strong background in science education having spent the early part of his teaching career as a physics teacher.
From mathematics we interviewed Celia Hoyles in December 2009. Hoyles has been Professor of Mathematics Education at the Institute of Education, University of London since 1984 and was the UK Government’s Chief Adviser for Mathematics between December 2004 and November 2007. She is Director

of the National Centre for Excellence in the Teaching of Mathematics in England.
From science we interviewed Peter Campbell in March 201l. Campbell is a highly experienced physics teacher and curriculum developer having worked for both the Nuffield Curriculum Centre as part of the 21st Century Science development team and the Institute of Physics as course tutor for the 40-day physics in-service training course, part of the 'Science Additional Specialisms Programme' that helps practising chemistry and biology teachers to become effective physics teachers.
Their insights into 'looking sideways' gave examples of teaching in which the teaching of one STEM subject took into account what was being learned in other STEM subjects.
To provide an international perspective we have asked teachers from Israel, Argentina and Brazil to comment on STEM secondary school education in their countries and we use this commentary to further explore two possible futures for STEM: one in which there is little or no looking sideways and one in which dynamic and synergic relationship between two or more of the contributing subjects.
Comments on STEM education in Israel we obtained from Ronit Peretz, a science and mathematics teacher at Rabin High School in Kiryat Yam and Ella Yonai who teaches science at the Sha'ar Ha Negev High School. Comments on STEM education in Argentina were obtained from Marcos Berlatzky and colleagues at the ORT Technical School in Buenos Aires. Comments on STEM in education Brazil were obtained from Vitor Soares Mann, Chief of Science and Biotechnology's Laboratories and Professor of Introduction to Technology at Instituto de Tecnologia ORT of Rio de Janeiro. All these commentators were invited delegates at the World ORT Hatter Technology Seminar on Integrated Approaches to STEM Education in London October 2012.

Results

Key points from the interview with Torben Steeg

For Steeg it was important that science education gave pupils an understanding of scientific method, or, even better, inculcate scientific thinking and if this was in fact the case this would give pupils the ability to approach a question in design & technology with a desire for empirical evidence; the attitude of 'let's find out'. He was concerned that the use of science might unnecessarily complicate matters if it required pupils to understand, for example, all the science behind the performance characteristics of the components they are using. This led Steeg to consider the use of chooser charts (Nuffield Design & Technology 2000). These are charts which describe the performance characteristics of components or materials or the usefulness of particular techniques. Their aim is to provide pupils with the information they need to make informed design decisions either unaided or with minimal support from their teacher. Steeg was clear that chooser charts aren't a substitute for all knowledge – pupils will need to know something to make sense of chart content and be able to use it appropriately. A key question is 'When will science knowledge be needed?' And this is exactly as Steeg pointed out at the beginning of the interview where being comfortable with using scientific thinking could be useful.

Key points from the interview with Celia Hoyles

Since measuring is a fundamental part of both mathematics and design & technology Hoyles thought it would be an area of exploration likely to be of mutual benefit. The interview moved quickly on from the mundane 'measuring length in millimetres in design & technology versus centimetres in mathematics' to the more positive arena of collaborating over the designing and making of a measuring device of some kind, suitable perhaps for Year 9 pupils. She wondered about pupils designing and making a weighing machine to meet an identified need in school e.g., a weighing machine that can be used in the school prep room to weigh small animals. Here the nature of the artefact immediately suggests mathematical thinking: understanding the range of measurement, an appropriate scale, calibrating the device, understanding the need for, and demonstrating reliability as well as other considerations, such as ease of use and comfort/minimal distress for the animal being weighed. Developing such a device might involve calibrating the stretch characteristics of a range of elastic bands such that the device could operate over a wide range of loads. Hoyles thought this was an example that would be worth mathematics and design & technology teachers discussing. However, Hoyles did raise a word of warning: it would be important not to impose constraints on the design & technology that rendered the task non-authentic. She thought it was very important to be aware that making the mathematics more visible might in some cases be counter-productive for the design as it introduces constraints that are just too artificial.

Key points from the interview with Peter Campbell

This interview was carried out in the context of a professional development session for physics teachers

concerning links between physics and design & technology. Campbell justified the interaction of physics education with design & technology education as follows:
physics is not an isolated discipline. It is important to make connections with other subjects explicit while teaching physics, because this can stimulate new interests for pupils or enhance their existing interests. Without help, few pupils manage to see such connections. Connecting physics to other curriculum subjects helps keep the physics curriculum broad. A school physics curriculum that focuses too narrowly on general principles and mathematical models will deter most pupils from engaging. As well as being important for pupils, it is also important for the physics teacher to make connections with other subjects. The viewpoint of other subjects can give fresh insight into a physics topic. For example, understanding the mechanical properties of materials in physics is enhanced by engaging with design & technology perspectives such as manufacturing processes, cost, and availability.

In terms of activities that might provide links with design & technology and have appeal to physics teachers Campbell identified the following:
Exploring the Peltier Effect: This phenomena is not included in most high school physics courses but it is intriguing and worth investigating. It can easily become the basis for developing a useful artefact. Philip Holton, a design & technology teacher in England has done this (Barlex 2013) using the results of a science investigation of the Peltier effect as the basis for designing and making heating or cooling devices.
Exploring the behaviour of a small paper helicopter: This is a well known activity in which making observations and taking measurements is challenging. This requires repeated observations, the use of scatter graphs to make sense of the observations and video capture with slowed-down playback to observe details of the phenomenon. Here again there is an opportunity to use the phenomenon observed as the basis for an artefact – a simple helicopter toy that could be used to 'land' small figures that jump from heights.
Investigating a turning toy made from two discs of different sizes at opposite ends of a wide shaft: This activity provides the opportunity for a very open-ended investigation. Findings about the behaviour of the toy could easily be used in design & technology lessons to inform the design of such a toy, perhaps leading to a toy in which there are wheels of different sizes with different positions of attachment (Nuffield Foundation 2000).

A future if STEM subjects stay in their silos
If science is to adopt a position in which it is relatively isolated from other STEM subjects then it will be important to find ways to make science attractive to students without recourse to links with other STEM subjects. Ella Yonai advocates an aspirational approach for students aged 14 years and uses the national pride in Israel's space achievements in her science teaching. The aspiration is that the student, wherever they are from, could one day be part of their country's space programme and become an astronaut. If this is something students wish to pursue then understanding science will be important to them. Ella has developed a science programme around meeting the needs of a space traveller. Each topic is taught in a two-hour class but within the school timetable. Ella hopes that this programme will be able to bring students closer to science and believes that learning in such a hands-on way, creating and exploring science, will help the students find the practical connection they look for in science lessons. And she believes that at the end of the school year when it is time to choose a specialty in high school, some students who had never consider it before, may choose a scientific or a technological direction.
If technology is to adopt a position in which it is relatively isolated from other STEM subjects it is important that it has a clear identity. In Argentina Marcos Berlatzjy and colleagues have noted there are three very different conceptions in operation and yet in only one of these is technology conceived as a body of knowledge different from other areas with its own unique paradigm which requires specialist teachers and dedicated spaces. This approach necessitates the identification of dominant features within the paradigm. So far two such features have emerged. In the first, design is seen as dominant. This concerns not only the invention and production of objects or products, but incorporates a broader look at the definition of solutions to transform situations that may include services or, even, production processes. In the second feature, a systems view dominates which transcend particular technologies and can be used whatever technological discipline is under consideration. It remains to be seen whether either of these paradigms becomes the prevailing orthodoxy or whether they will be able to coexist comfortably within a technology curriculum that sees itself as providing a unique body of knowledge.

A future if STEM subjects 'look sideways'
If the curriculum encourages a dynamic and synergic relationship between two or more of the contributing

STEM subjects this will have implications for the way such subjects are taught. Ronit Peretz argues for the importance of relating science to technology:

When science and technology subjects are taught as separate disciplines, students are not aware of the link between the different contents and are not able to develop a systematic comprehensive view of the world around them. Therefore, it is very important to teach science and technology in a broader context regarding mathematics and engineering. Integrating STEM subjects: Sciences, Technology, Engineering and Mathematics, together into one interdisciplinary subject – STEM – unlike learning them independently, can break down the barriers between the school and the outside world and reduce the gap between learning at school and the real life. STEM education can provide opportunities for students to understand in general the scientific and technological principles as well as the relationships between science (the natural environment), technology (artificial environment) and society. Understanding these relationships can teach them a lot about their lives, the possibilities and benefits on one hand and problems or limitations on the other, so they will be able to discuss issues and reach responsible decisions about their present and future life based on their knowledge. Using interdisciplinary teaching-learning processes will expose the students to genuine daily life problems, dealing with them and finding solutions. This will make the study of science and technology more relevant to the student's life and they will better understand the scientific – technological world around us.

Vitor Soares Mann sees the combination of formal and informal education as a useful way for 'looking sideways':

In short, we can understand that the STEM philosophy can be adapted to two different, but equally important, pedagogical conditions. The formal environment ensure students an egalitarian education, allowing everyone to have access to the same content. The informal environment plays a complementary role, using the previously established knowledge in formal education to offer students a context of greater autonomy. Consequently, we must understand the two scenarios as complementary, one environment of security and stability and other of creativity and innovation. Although methodologically different, these environments are capable of absorbing STEM philosophy as an ideology, as a social responsibility; the responsibility to provide students a complex and integrating formation, committed to the construction of critical subjects.

Note that the results presented above are a subset of the data used by Banks and Barlex (forthcoming).

Discussion

Hargreaves (1998) in considering the knowledge creating school has identified four features needed in schools that undertake significant curriculum development. He argues that they should be considered as knowledge-creating schools and as such:

- investigate the state of their intellectual capital
- manage the process of creating new professional knowledge
- validate the professional knowledge created
- disseminate the created professional knowledge.

STEM provides an opportunity, some might say an imperative, for teachers to create new professional knowledge. Paralleling the features that Hargeaves identifies those teachers who wish to engage in STEM through looking sideways in the curriculum will need first to investigate the state of their intellectual capital; i.e. understand the nature of their own discipline, its learning intentions and methods of teaching and assessment. Then in creating new professional knowledge they will explore how they might teach their own subject taking into account what their pupils are learning or have learned in other STEM subjects. The basis for this is an extended series of professional conversations which moves through exploring possibilities to identifying specific examples of teaching/learning activities which can then be tried out. In pursuing the conversations whilst it will be important to be realistic it will also be important to be aspirational and imaginative. This will need nurturing for as Hargreave (1998 reminds us, good ideas can be fragile and need protection especially when they come from new of junior colleagues. He emphasises that 'cynics kill knowledge creation' (p31).

The next step is to validate this knowledge through teaching and evaluation. It may take several iterations before the evaluation reveals worthwhile success. And finally successful endeavours will need to be disseminated. There will be both formal and informal opportunities for this. One important formal opportunity is publishing in professional association journals. An informal opportunity of growing significance is presentation at teach meets, teacher meetings organized by teachers at short notice through social networking allowing only very short presentations (Smith 2013).

Conclusions

This small study has shown that there are opportunities for teaching one STEM subject taking into account the learning that has happened or is happening in other subjects and that this approach of 'looking sideways' in the curriculum will have benefits for pupil learning. This approach can be considered through the lens of teachers creating new professional knowledge and in this way leads us to endorse the idea that teachers are crucial in pursuing a SETM curriculum in which there is interaction between the subjects. For as Black states

> "It must be recognised that teachers are the sole and essential means to educational improvement. If they do not share the aims, and do not want to do what needs to be done, it cannot happen effectively."
> Black in Dillon and Maguire, (1997, p 60)

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