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Teacher Knowledge and Understanding of Design and Technology for Children in the 3-11 Age Group: A Study Focusing on Aspects of Structures.

Eric Parkinson

Introduction

Teacher background knowledge and understanding has probably been an issue for providers of initial as well as in-service teacher education for as long as teachers have been formally prepared for their profession (Bennett, Summers, & Askew, 1994; Reynolds, 1989). In the UK a wealth of training documentation concerning background knowledge for teachers underpins this concern (Department for Education and Employment, 1998). The issue of teacher background knowledge in curriculum areas such as science and technology is an intense one. Matters such as teacher confidence and perceptions of a relevant knowledge base (Holroyd & Harlen 1996; Kruger, Palacio, & Summers, 1990) and the sheer pace of change in our technological and scientific environment, serve to challenge all existing and intending teachers (Rannikmäe, 1998).

This article is concerned with issues surrounding the depth and level of detail of knowledge that teachers of children in the age range of three to eleven years may need in order to teach certain aspects of design and technology with confidence and accuracy. The study is focused on aspects concerning student teachers' understanding of structures and associated scientific ideas on force. The article thus attempts to determine to what extent those who aspire to become teachers are aware of the role of certain scientific concepts in underpinning aspects of Design and Technology activity in English and Welsh schools. The article then raises questions about the implications arising for future professional and curriculum development.

The place of structures in the curriculum: Professional concerns

Design and technology can be seen as having a considerable body of knowledge with which skills interact and from which product outcomes may duly arise. Within the National Curriculum for England and Wales (Qualifications and Curriculum Authority and Department for Education and Employment, 1999), this body of knowledge and understanding of materials and components can be classified broadly within areas such as the working characteristics of materials and combinations of materials; use of mechanism including control, and switching with electric circuits.

These areas embrace an ocean of conceptual matters and real-life experience

Eric Parkinson (e.f.Parkinson@canterbury.ac.uk) is on the Faculty of Education, Canterbury Christ Church University College, Kent, United Kingdom.

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and are founded on the inter-relationships between the great scientific abstractions of matter, energy and force. The knowledge-based dimension of this article, which is focused on the understanding of structures, thus embraces the conceptual domains of force and matter.

Structures are necessarily encountered in many aspects of children's activity in designing and making. Activities involving the arrangement of materials so they retain their shape when subjected to forces will have a structural dimension. This applies as much to modeling a house in card or paper as it does to the baking of bread or the building of a car or tower with a construction kit: all these products retain their shape despite the influence of say, gravitational or frictional forces. The publication of a subject-specific Design and Technology guidance scheme of work by the UK government agency, the Qualifications and Curriculum Authority of the Department for Education and Employment. (QCA/ DfEE) underpins the relevance of this broad influence of structures on designing and making activity. Within this scheme, nine out of the range of 24 classroom planning units feature some aspect of structures as the main or shared focal point. It is worth noting however, that the QCA/ DfEE scheme of work was founded upon a pre-1999 (Department for Education, 1995) version of the national curriculum for England and Wales and does not reflect the revised, relatively low density level of knowledge and understanding now required of children aged 3-11 engaged in design and technology in English and Welsh schools (DfEE/QCA, 1999).

For comparison from an American perspective, a set of Standards now define and detail content for the study of technology to significant depth. Areas specific to the understanding of structures (for children in Grades 3-5) can be found under Core Concepts, Standard 2, where it is noted that "The properties of a specific material determine whether it is suitable for a given application" (ITEA, 2000, p. 35), and in Standard 20, (children in Grades K-2) Construction Technologies, where "The type of structure determines how the parts are put together" (ITEA, 2000, p. 192).

The QCA/DfEE guidance materials have been widely adopted by schools for children in the age range 3-11 in England and Wales. It is this widespread adoption of a government-approved scheme of work that would appear to bring with it a considerable classroom commitment to the teaching of structures.

Concern for teacher understanding in the area of structures has become evident with the publication of formal teacher education and self-study materials by higher education and UK government agencies (Kruger, Palacio, & Summers, 1991). These materials have been intended for use by teachers in schools, often using classroom ideas from children as links to the misunderstanding of concepts relating to forces held by adults, and thus of course, teachers. A self-study guide on Forces (National Curriculum Council, 1992) has within it a dedicated section on structures to assist teacher understanding. This resource is prefaced by a carefully worded caveat to the effect that the purpose of the material is to extend teacher knowledge and understanding and that it is not suitable for direct use in the classroom. Clearly,

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some degree of background knowledge beyond the working level of children is seen as desirable.

Teacher understanding specific to design and technology has been highlighted by the UK Teacher Training Agency (1998) with the publication of self-assessment texts intended to provide diagnostic feedback for serving teachers.

Recent changes in the requirements for the qualification of teachers in England and Wales have further underpinned this subject-specific deepening of teacher knowledge. All student teachers in England and Wales now have to comply with certain specified Standards regarding background knowledge in subject areas if they are to gain qualified teacher status. It is interesting to note that nationally defined curriculum specifications for children's learning have been reduced and yet the reverse is true for teachers. The government-specified standards in science require that trainees for school teaching of ages 3-11 should "...identify how the different areas of science relate to each other (unifying principles and concepts), so that they can make conceptual links across the subject, present pupils with a coherent perspective of the subject matter taught, and ensure progression in pupil's learning" (DfEE, 1998, p. 77). This is a significant demand on student teachers. Clearly it is insufficient for them to simply possess knowledge of say, forces or energy. Instead they should develop an understanding of the *interaction* of these underlying principles. This is a conceptually challenging requirement.

Work embracing ideas on structures can be seen as having dual purposes in the assembling of knowledge and understanding. It may serve to combine knowledge and experience of the properties of materials with an understanding of forces acting on the materials.

At a classroom level, when children are engaged in design-and-make activities, such as modeling buildings in card or paper, they are using a sheet material that can be shaped so that it is able to offer resistance to certain forces. As a consequence, the card can maintain its shape for presentational and structural purposes. The act of putting a crease or bend in a piece of sheet material is significant and the rationale behind this action may be based on the notion that "bends make certain things stronger." In the light of ideas such as this, questioning and observation of actions of student teachers in design and technology workshops has provided some useful evidence. It has shown ways in which thinking and past experience have played a part in shaping responses and serves to indicate levels of conceptual grasp. In particular, some previously formed ideas that student teachers carry to new learning situations can exert significant influence.

Aspects of Misconceptions: A Literature Review

A considerable research arena has been built up around the issue of what, in literature stemming from science education, cognitive science, and developmental psychology, may be termed "misconceptions". These have been succinctly described as situations arising from the ways that "children and adults

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construct their own ideas about natural phenomena that are often different from scientists' ideas" (Suzuki, 1998, p. 130).

The term "misconception" is but one of many descriptors for this phenomenon. Other terms include "preconceptions" (Ausubel, 1968) and "children's ideas" (Driver, Guesne, & Tiberghien, 1985; Osborne & Freyberg, 1985). Generally these descriptors can be seen within the scope of a theory of knowledge and learning recognized by the genetic epistemologist as one of continuous construction since "in each act of understanding, some degree of invention is involved; in development, the passage from one stage to the next is always characterized by the formation of new structures which did not exist before, either in the external world or in the subject's mind" (Piaget, 1970, p. 77).

The philosophical underpinning of the theory of continuous construction, or constructivism, contrasts sharply with other perspectives. Among these can be identified the notion of empiricism, in which discoveries, although new to the subjects making them, are already perceived to have existed in reality and did not result in the construction of new realities. Another view is that of the nativist or a priorist. This asserts the predetermination of forms of knowledge inside the subject.

Misconceptions can be seen to arise as part of the process of continuous construction. They represent mental models, constructed by individuals who have used whatever evidence has been at hand, that are at odds with the views held by the majority of members of a community of knowledge.

A significant body of research has been conducted on the basis of investigating children's misconceptions. However it is reasonable to assume that misconceptions reside in adults, too, and that inappropriate ideas left unchallenged in children will persist into adulthood.

A perception within the constructivist view of education is that appropriate elicitation of ideas may expose misconceptions. Subsequent learning experiences may provide settings to challenge misconceived ideas and so promote conceptual shift towards that held by a majority of participants in a community of knowledge, such as scientists (Bentley & Watts, 1994; Ollerenshaw & Ritchie, 1993). It could be said, for example, that the more "scientific" an individual becomes may be due to the enhanced opportunities they have had to gain and analyze evidence and set this against the ideas they already hold. This cannot happen in isolation. Opportunities to discuss ideas and effectively form localized communities of knowledge through small-group discussions would appear to be part of a "sense-making" pathway to enhanced understanding (Shapiro, 1994, p. 182).

The notion of constructivism can be taken further into a broad philosophical arena with the assertion that, "Radical constructivism, thus, is radical because it breaks with convention and develops a theory of knowledge in which knowledge does not reflect an "objective" ontological reality, but exclusively an ordering and organization of a world constituted by our experience" (von Glasersfeld, 1987, p. 199). Such construction of the individual's subjective reality possesses not only elements assembled through personal actions, but also

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the influence of prevailing social and environmental conditions. A logical, and perhaps disturbing endpoint of this line of thought can be determined. If social and radical constructivism deny the existence of an objectivist, ontological reality, then this metaphysical and epistemological denial "effectively opposes the basis of knowledge for science and social studies education as well as the knowledge which helps to structure the organization of schooling itself" (Fleury, 1998, p. 160).

The notion of strength and how and where forces may act are central to student understanding of structures. Student teachers will carry their own ideas about these concepts and some of them will be misconceived. One of the principal misconceptions revolves around the notion of "reaction forces." Learners do not readily appear to recognize that forces act in pairs and that as a consequence of a force acting upon a structure, the structure will react in opposition to the applied force. This can be seen as a fundamental plank in terms of the pathway to understanding since "Only when more than one force is recognized can thinking about equilibrium start" (Simon, Black, Brown, & Blondel, p. 277).

Minstrell (1982) in his study of high school physics students demonstrated that only half of a classroom sample suggested that a table might "push back" on an overlying book. From the Minstrell evidence it seems that even young adults in the specialized learning environment of a physics class will cling to previous ideas. Within the development of student teacher's expanding body of knowledge it is possible, then, for a range of misconceptions to persist into and beyond their training environments and thus indeed into the classroom. Research evidence collected from children in the 7-11 age range for the SPACE research reports (Russell, McGuigan, & Hughes, 1998) similarly substantiates the widely held misconception relating to reaction forces.

On leaving training, to what extent will misconceptions significant to the future teaching environment be still embedded in the mind of the teacher?

Problem solving as the context for the Study

The role of problem-solving has early links with the evolution of "technology"—later resolved from information technology to become Design and Technology (Department of Education and Science/Welsh Office, 1990) in the English and Welsh curriculum. Various key texts have had a profound influence on shaping the minds of young designers, their teachers, and curriculum developers alike. Notable among these is Johnsey's (1986) model of problem-solving in school science with its fundamental contextual links between technology and science.

For the purposes of this study, a problem-solving setting was utilized. Problem-solving as a means of learning has a host of benefits including task ownership, cross-curricular activity, and communication enhancement (Watts, 1991). All of these performance traits contributed to the conduct of this study. A group-based social setting for problem-solving was employed which had numerous benefits in terms of role-finding and the sharing of ideas (Lave & Wenger, 1991; Rogoff, 1995). Furthermore, within these social settings,

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language flowed freely and informal tutor eavesdropping, as well as more direct questioning of groups, revealed much about the how the quality of thought, prior experience, and on-task conceptual re-shaping had impacted the problem-solving situation.

Study Participants

The subjects for this study were drawn from a teacher education background and were engaged in the first year of a Bachelor of Arts Qualified Teacher Status (BA QTS) degree course at an English university college. The BA QTS degree is a three- year program specific to the training of teachers who will teach in the 3-11 grade levels of education. The subjects were drawn from two student cohorts taking design and technology short courses. These 20 hour courses are taken by all students in the first year of the BA QTS and are part of a first year introduction that stresses curriculum breadth.

The subjects (n=40) were predominantly female (n = 37), reflecting the general recruitment pattern into the BA QTS. Just over half of the sample (n = 22) were between the ages of 18 and 21 years. Those over the age of 21 are classified as "mature" students in English student statistical data.

The nature of the problem framed for student teachers

The problem was focused on an apparently simple bridge-building task, using limited materials. The use of limited materials had a direct effect in terms of guiding participants towards a variety of structural solutions. The problem was based upon an idea from a seminal work produced by the Berkshire Local Education Authority featuring child-centered designing-and-making, problem-solving situations sketched out for direct use in classrooms.

The focal point activity offered to students in this study was actually an extension of one of the examples taken from this text. The problem, centered upon a popular children's folk tale entitled "The Three Billy Goats Gruff," is framed with these words:

> "The Troll was so angry at the three Billy Goats Gruff crossing the bridge and eating his green grass that he demolished the bridge. To stop the goats making a new bridge he removed all the wood from the river bank and has left some paper behind because he does not think the goats could make a paper bridge" (Berkshire Local Education Authority, 1986, p.37).

Conditions are then attached to this task for children. They are to model the bridge across a gap of 25 cm. They can use only 3 sheets of letter size paper (210 X 296 mm) and goats made of modeling clay of specified masses must be able to make the crossing.

For the purposes of this study the Billy Goat problem was utilized for work with student teachers. Changes in the structural specification were made in order to provide challenge at an adult level. Student teachers were thus required to work to an enhanced set of performance criteria attached to the following task: "Design and make a structure across a 40 cm gap so that it may be traversed by a (specified) simple vehicle. The structure must be capable of supporting a 50 g

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mass at its center, but not when the vehicle is crossing.” Additional design criteria were specified to enhance the problem-solving setting such as: “The structure will enable you to give the simple vehicle one push on one side of the gap. It should then traverse the gap on its wheels so that it arrives on the other side still traveling on wheels” and “ You may only use paper clips and A4 sheets of paper to build the structure.”

Further conditions on construction techniques were specified such as “You may not use any other materials. You may not pierce the sides of the intervening gap to fix paper clips. You can cut the paper with scissors.” Finally economic specifications were added such as “Paper clips cost £3 each. Paper costs £10 per sheet” and “ The budget limit for the task is £100. You may experiment with unlimited supplies of paper and paper clips —the budget applies to the *finished* structure”.

Further challenge to the problem-solving task was provided with an economic dimension. Although a budget had been set, clearly if bridges could be constructed which met the criteria and undercut the £100 limit then these could be seen as being economically advantageous. As an ongoing task, students who met the initial criteria refined their designs and considered other possibilities with lower cost implications.

Study Method

Students were encouraged to work in pairs. Observation and final-outcome product assessment provided the main basis for gathering the data. Informal eavesdropping on conversations and questioning was undertaken to provide supporting evidence to the main purpose of this study that concerned the production of artifacts. One of the key weaknesses in the method chosen was the moderating effect of students working in pairs: individual ideas inevitably were subject to negotiation, and there was a “cross-fertilization” effect of pairs of students seeing, reacting to, and incorporating the work of colleagues.

Data Collection

Data were collected as informal notes on conversations, systematic recording of student teacher definitions of the term “strong,” and artifacts arising from the problem solving events themselves.

There were difficulties in terms of expressing the data concerning outcomes from the artifacts produced since they were not simply final designs, but a range of intermediate designs of which some were abandoned for totally new ideas and others progressively modified to become new forms of structure. For this reason, broad classes of designs are described in the following results, with appropriate notes on design transformations as they presented themselves.

Language data were collected through a survey. Subjects engaged in the bridge problem-solving activity were asked to record their definition of “strong.” This process of data gathering was achieved on an individual basis with subjects recording their definitions on pieces of paper and not revealing these to colleagues.

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Results and data analysis

Artifacts

Outcomes of the problem-solving activity considered from the perspective of artifacts can largely be categorized into three broad classifications. The first outcome was one in which a tubular structure had been devised through which the simple vehicle could travel. A variation on this theme was a pair or more of longitudinal tubes onto which paper decking was laid. Tube-based solutions were one of the most popular modes of problem-solving responses to the bridge scenario. Sometimes students made tubes with a triangular cross section rather than one that was circular.

The second outcome consisted of structures that had been assembled with multiple concertina-like (accordion-like) folds. There were two variations on this theme. With variant one, the concertina arrangement was disposed so that it was at right angles to the long axis of the bridge. These folds were often incorporated as a core to a "sandwich" with paper decking above and below. This first variant was inherently weak. Failure to achieve a solution with this first concertina variant led to a second concertina solution in which the folds were arranged longitudinally to the alignment of the bridge. Entry ramps provided vehicular access to the structure this being necessarily raised to accommodate the thickness of folds.

The third outcome, often arrived at by refinement and simplification of the other routes, was the simple folded U-shaped structure where vertical slab-like sides offered a means of simultaneously retaining the crossing vehicle and providing resistance to a variety of forces as the vehicle passed over. An entry ramp was not required. Of all the above constructions, the U-shaped variant was the simplest, strongest, and least often attempted. In design terms, it was instructive to watch the shift in thinking that directed students toward U-shaped solutions. The two other variants invariably had some form of decking laid upon concertina or tubular elements. This decking might be simply full-width pieces of paper (from which a crossing vehicle would tend to fall) or paper with edges folded upwards to retain the vehicle in the act of crossing the structure.

Some students experiment with this added vehicle-retaining deck piece. In some cases they discarded the underlying structure of concertina pieces or tubes and simply explored the U-shaped decking on its own as a replacement structural element. Refinement of the decking, such as providing taller sides and longer overlaps of sheets of paper, led to the discovery of a new structural element, the U-beam. The U-shaped solutions utilized the fewest resources and undercut the budget limit of £100 by a surprising degree. This low-cost approach to the problem offers an example of an "elegant solution" (Gustafson, Rowell, & Rose, 1999, p. 37) by virtue of simplicity and effectiveness.

Language

Analysis of data concerning student teacher definitions (n = 40) showed that of the key words used as qualifications to help define "strong," the word used most frequently was "weight" (n = 19). Far less popular were the terms

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"support" (n = 7) and "force" (n = 7). In some cases the terms "strong" as well as "support" were used together in definitions.

Trailing well behind these terms were key terms such as "durable," "power," and "energy" (n < 3). Considering that the problem called for the loading of 50 g masses onto the structures, it was no surprise that the subjects derived definitions based upon weight.

Discussion

Problem solving and design

The limits to the use of resources in this task delivered significant dividends in terms of developing student teacher designing and evaluation skills. Students were compelled to consider the ways in which the materials—paper clips and sheets of paper—could be rearranged to become "strong," that is, to resist deformation. Patterns of behavior in which rearrangements are considered, tested, and rejected are consistent with the "serial development of solutions" problem solving pattern identified by Welch (1999) and the complex interactions of technological activity in terms of interactive strands of building, modeling, idea-generation, and understanding (Welch, 1997).

Johnsey (1993) similarly recognizes this complexity of interactions in the designing and making process with his analysis of pupil behavior in primary settings. As an example of problem solving, the task has great merit for there is no "right" answer: if the bridges perform in accordance with the specification that was set, then the task is completed.

Student understanding of forces and the structural strength of materials

Student teachers questions about the construction techniques utilized in the problem-solving settings outlined in this study invariably focused on the term "strong" when describing and justifying arrangements of materials. As has been indicated earlier in this account, changing the shape of materials –perhaps by folding or bending—is seen as a way of making a "weak" material such as a sheet of paper into a "strong" one. There are a number of issues that arise here.

Issue one—what is meant by "strong"?

The first issue is that most students did not readily articulate a link between the terms "strong" and "force." From the survey evidence regarding definitions of "strong" it was clear that the influence of the context, especially the load-bearing setting of the problem presented, guided subjects towards weight-derived definitions. Strength was predominantly seen as a quality that enabled the potentially deforming influences of weight to be resisted, yet weight was not readily articulated as an expression of force.

Issue two—what is meant by "weak"?

The second issue concerns student notions of paper as a "weak" material. Students had a tendency to justify their structural arrangements in terms of giving strength to the "weak" paper by actions such as folding or bending. The presumption of weakness in paper is perhaps directly related to an inadequate

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linking of the concept of strength to ideas on force. If strength is related to force, and if force is simply expressed in terms of pushes and pulls, then a "strong" substance – or structurally devised arrangement of that substance - is one that can offer resistance to various forces. Moreover, the resistance to force can be recognized in the effects of pushes and pulls. Some "strong" substances, like the keystone of a stone arch, can offer very considerable resistance to pushing forces. Sheets of paper, however, offer little resistance to pushing forces applied at each end. Some "strong" substances can offer considerable resistance to pulling forces and sheets of paper can certainly do this. Of course, all these terms are relative. Sheets of paper offer considerably more resistance to pulling forces that they do pushing forces

Where were the misconceptions?

It would seem that the sample of students reviewed in this study carried elements of part-formed knowledge into their problem-solving setting. Informal discussions with these student teachers suggested that this part-formed knowledge had been carried over from previous experiences, often from when they were children. These experiences embraced situations such as working with paper (for example, to achieve strength by folding), and pre-existing ideas on the nature of bridges, based perhaps more on what they look like than what they do. From a design perspective, misconceived thinking may have been imported from ideas on form (the "look" of bridges) into presumptions regarding function. Nonetheless, these experiences became fused into the new learning situation to produce not only physical outcomes, such as the bridges themselves, but also a deeper experience which yielded structural solutions based on corrugations, pipes, and U-beams as means of resisting various forces. This was despite the fact that students did not seem to be sure which forces were operating and where or how they were acting.

In particular, students seemed to make an intuitive (and appropriate) response to a structural problem in the sense of providing as much as possible of the building material (for example folded paper) for forces to act upon. They devised ways of "spreading the load"—in other words, they applied stress reduction measures. This form of intuitive response can be likened to the notion of "understanding the situation" (Donaldson, 1978, p. 37) in which the learner makes sense of events as they perceive them, not necessarily being aware of, or understanding all the factors that may be present. The misconception that paper was not "strong" could be related perhaps to an incomplete understanding of the nature of force and its inter-relationships with materials, especially when these materials were shaped in various ways. It is worth noting, of course, that the notion of strength is contextually bound. It was possible for students to perceive pushing forces acting on the paper: it buckled. Less obvious, but central to the structural context of the bridge, was the effect of pulling forces that acted on the paper, yet offered no visible clues to this situation. The notion that forces could be acting as reaction pairs was largely absent. Students had incomplete ideas of the way that a structure, or indeed a material, may "push back" against a force in order to maintain established morphological integrity.

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In a profile of the constructivist teacher operating in classrooms for children aged 3-11, it has been suggested that the teacher should have a prior awareness of the ideas that learners will bring to the learning situation and that they should "use pupils' ideas in the development of the lesson, as it happens" (Juca & Maskill, 1997, p. 13). In the light of this, the exposure of student teachers to their own misconceptions would seem most relevant. They need to appreciate that they may carry misconceptions in their own learning, as well as understand some of the most common misconceptions held by children. The study context outlined in this article is thus portrayed as an example of a way in which student thinking can be challenged and how classroom practices can be modeled in adult learning situations.

From a teaching perspective, the process of achieving effective conceptual shift is not straightforward. It has been suggested that this notion of conceptual change is complex and that "the altering or reorganization of existing schemata to account for new learning, appears to take place only under certain conditions. These conditions, as yet, are poorly understood when it does occur, conceptual change has been hypothesized to be the result of several interacting factors, epistemological, cognitive, and affective in nature" (Hynd, Alvermann, & Qian, 1997, p. 3).

Some specific strategies for enabling conceptual shift to occur have been assembled, particularly with reference to "anchoring examples" (Kruger, Palacio, & Summers, 1991, p. 125), that bridge understanding between intuitive beliefs and accepted scientific views. The broader nature of the learning landscape with respect to misconceptions in Design and Technology may prove to be a fertile setting for further investigation and development.

While trainee teachers working within the bridge-based project may have been immersed in an environment that involved scientific and technological ideas, they did not appear to formally acknowledge the linkages of their work to science. The relatively low incidence of the use of the term "force" in discussions is a key pointer in this respect. Instead, the term "strong" was employed and seemingly intuitive interpretations of the role of "strength" led to solutions, but little consideration given to what the term might actually mean.

This view of poor links to science is supported by a broadly similar study of construction with bridges, but undertaken with Year 9 pupils in Australia. Within this study it is noted that:

> Although some of the students interviewed from this classroom demonstrated surprisingly good understanding of some of the scientific principles associated with the bridge project, three of the five students did not think their scientific knowledge was useful during this project and one other student identified creativity as the only aspect of science that he used. One possible explanation for this lack of recognition of the science aspects of the technology project is that students saw science more as a content oriented subject rather than a skill or a process oriented subject (Venville, Wallace, Rennie, & Malone, 1999, p. 45).

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If science is seen as "different," then scientific ideas embedded in broader fields of experience may be seen to be different or irrelevant—or perhaps, may even fail to surface as ideas at all.

Conclusions

On the whole it would seem desirable that misconceptions are challenged and reconstructed in student teacher training sessions. The more active student teachers become in the construction of their own knowledge, the more able they may be to appreciate the breadth and significance of constructivist learning theory and how it may be applied to enhance the learning of the children they will teach. Additionally, the more that the knowledge of the student teacher is constructed along the lines of the scientific community, the less likely it is that these future teachers will foster the development of inappropriate conceptual frameworks in the minds of the children they will teach.

This article has exposed some of the issues in which science plays a part in informing technological outcomes. In light of this, perhaps closer ties between science and technology are desirable as part of a cross-curricular approach. Layton (1993) exemplified aspects of this relationship with his multi-layered images of science as a cathedral. For the technologist, this venerated building can house natural laws to which technological devices must comply; or it may act as a quarry in which to search out items that might be of use. At another level, Layton likens the cathedral to a company store, housing a body of accessible, organized products. From all of these settings, science may nourish technology and technology in turn may usefully provide the contexts within which scientific ideas may grow and develop.

In the past, notably through debate promoted by Black and Harrison (1985), there has been a tendency to identify differences between science and technology. This in turn has led towards the teaching of separate subjects at the expense of cross curricular work. This is especially true relative to how the national curriculum in England and Wales has been interpreted for the 3-11 age group.

However, it could be that a closer association between science and technology within the curriculum of England and Wales would pay considerable dividends. Johnsey (1999) has proposed an enhancement of such links, but it is largely in the hands of schools as to whether subject-driven content will be maintained at the expense of possible wider benefits across the curriculum. The recognition of the role of scientific and technological literacy (STL) as a medium for curriculum change is fundamental. Significant efforts to add STL to the global curriculum (Association for Science Education/ UNESCO, 1999) are underway, and the operationalization of this thrust is underpinned by a range of international agencies. STL is, however, a limited curriculum model coming from the science-with-technology stable. It is not a cross-curricular thoroughbred. Nonetheless, STL has the capability to add technological contexts from everyday life to science-based learning situations. From this starting point, learning in science may be seen to gain relevance and to have a part to play in developing problem-solving and decision-making among students. In terms of

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teaching and learning, then, STL may possess potential to provide added impetus to technology education.

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