Promoting Transfer and an Integrated Understanding for Pre-Service Teachers of Technology Education

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Abstract

The ability of pre-service teachers (PSTs) to transfer learning between subjects and contexts when problem solving is critical for developing their capability as technologists and teachers of technology. However, a growing body of literature suggests this ability is often assumed or over-estimated, and rarely developed explicitly within courses or degree programmes. The nature of the problems tackled within technology are such that solutions draw upon knowledge from a wide range of contexts and subjects, however, the internal organization and structure of institutions and schools tends to compartmentalize rather integrate these. Providing a knowledge base and strategies to enhance PSTs' awareness of and skills in transferring knowledge may allow for a more integrated understanding to develop. The importance of developing this ability to transfer knowledge is heightened as PSTs will, in turn, be responsible for developing the similar capabilities of their future students. This paper begins by considering problem solving in technology education and some of the issues associated with learning transfer. Thereafter, a framework and strategy for better integrating learning between courses is described and forms the basis for developments in an initial teacher education degree programme for technology education. Provisional data from evaluations and PSTs' work indicated a positive effect in enhancing their thinking and additional data collected in the form of questionnaires, interviews and course work further illuminate this finding. It is argued that the development framework and approach enhances PSTs' mental models of teaching technology and offers a significant step forward in promoting skills in the transfer of future learning between subjects; something increasingly critical for 21st century STEM Education.

Keywords

learning transfer, problem solving, teacher education, technology education, pre-service teachers

Problem Solving and Transfer in Technology Education

Introduction

Savage and Sterry (1990), argue strongly that problem solving has been identified by many as the central method through which students learn about and gain an understanding of technology.

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The skill of problem solving is also a critical thinking skill necessary for addressing issues related to technology and for developing effective solutions to practical problems (Custer, Valesey & Burke, 2001). "Design and problem solving are essential components of technology and technology education" and that this forms a distinctive characteristic of this subject area (Potter, 2013, p.69). Research exploring problem solving continues to expand our understanding on its role and execution within technology education (Hong, Chen, Wong, Hsu & Peng, 2012; Tseng, Chang, Lou & Hsu, 2013; Middleton, 2009), signifying not only that we have much still to learn, but also that it constitutes a critical capacity for PSTs of technology education to develop proficiency in, both as developing technologists and as a future teachers in the field.

This paper explores shifts that have occurred in the thinking of PSTs after taking a course developed to enhance skills in knowledge transfer and problem solving. A framework for enhanced transfer was developed from a detailed review of literature, and was used as a basis to develop a course-based intervention. A two-stage data gathering approach was employed and findings in the areas of confidence, understanding, transfer skills and mental models of teaching are reported in terms of PSTs as developing technologists and as developing teachers. In this context, shifts in thinking and mental models are seen in a similar manner to the concept of shifts posited within the theory of transformative learning (Mezirow, 1997).

Knowledge Transfer

There are two key areas of consideration and challenge associated with bolstering the types of knowledge, skills and capacities necessary for effective problem solving in technology.

Technology education encompasses a comparatively broad range of problem types and contexts. Twyford and Järvinen (2000), discuss the fact that these range from very well-defined problems with single, known answers to open-ended problems in which a range of solutions are possible. As well as cultivating expanded social interaction, more open-ended problems tend to broaden the ranges of knowledge and experience school students are required to draw upon (Twyford & Järvinen, 2000). An alternative distinction in relation to context, can be found in the three-part typology of problems in technology education offered by Rasinen, Virtanen and Ikonen (2012) in which problems have either one or a small number of solutions, are everyday life or *real* problems, or appear in the form of abstract problems where the intention is to develop problem solving skills. It is not unreasonable to argue that this variation in problem definition and context, in conjunction with learner characteristics, will heavily influence the type of problem solving activity that is undertaken in response.

Second, Dixon and Brown (2012) discuss the fact that school students fail to make connections and transfer skills between subject areas and that, according to a report published by the Committee on Science, this is because there are insufficient opportunities for them to engage in authentic problem solving that prepares them for that which they would encounter outside of school (Committee on Science, 2007). The typology offered by Rasinen et al. (2012) certainly suggests a strong role for technology in addressing this. Structurally, such transfer between different subject areas within a learning activity can be seen as acting horizontally; henceforth referred to herein as *horizontal transfer*. Though the term is prolific, it is noted that connotations of the word *transfer* suggests a clean, objective shift from one place to another, something Banks and Plant (2013) discuss this with respect to neighboring subjects such as science. They note that it is oversimplistic to regard scientific knowledge as simply *applied* in technology; and that, in many cases, objective scientific knowledge plays a very minor role and that it is continually re-contextualized to reduce its abstraction until it is no longer useful in facilitating a practical outcome. The idea that knowledge is not simply applied is echoed by Helms Jørgensen (2011) who argues that rather than being *transferred*, knowledge is actually transformed. Banks and Plant (2013) concurrently point out that, in technology, knowledge is often drawn from a range of domains, including economic and social, and that technology teachers often assume that transfer from these happens quite readily, which is not the case (Dixon & Brown, 2012).

Kilbrink and Bjurulf (2013) convey a similar message through discussion of vocational learning. They highlight transfer from the learning environment to the workplace as critical, but that this is made problematic because schools attach different values and purposes to the learning than workplaces do. This is considered herein as *vertical transfer*. Despite this being sought after to maximize the utility of learning in general, it is particularly salient for technology insofar as the subject has the capacity to reflect authentic practice (Potter, 2013).

It is clear then that technology, as a curricular area, offers notable potential in providing authentic problem solving contexts that can foster students' abilities to make meaningful links and transfer learning. Indeed, learning within such contexts, with the potential to afford students a more *integrated understanding* of subjects and domains can be seen as integral to STEM education in general, and in equipping students to engage with the demands of future jobs in related sectors. It is, however, an ability to transfer learning into different contexts that cultivates just such an understanding, and this has been shown to be often ineffective and challenging (Brown, Collins & Duguid, 1989; Perkins & Salomon, 2012); and readily presumed by many educators to occur automatically (Alexander & Murphy, 1999). Notably, such challenges with transfer were shown by McCormick (2004) to feature specifically within areas of technology education, many of which the PSTs in this study will go on to teach. The examples cited demonstrate that some task contexts can mask understanding and inhibit students linking knowledge.

The Value of Skills for an Integrated Understanding

A number of studies have attempted to identify factors that affect people's ability to transfer what they have learned between subjects and situations in formal educational settings. Barnett & Ceci (2005), argue that task, learner and organizational features all contribute to the *transferability* of that which is learnt. Engle, Lam, Meyer and Nix (2012), for instance, argue for expansive rather than bounded framing of tasks to promote positive transfer, however the organizational features cannot be underestimated. From the outset, both schools and universities have an internal structure that exerts a strong tendency to compartmentalize subjects and learning, something that LaPorte and Sanders (1993) attempt to address. They attempt to break down these boundaries through an integrated model of STEM education in which technology classes act as the host context for the application of learning from other subjects. This rationale supports learners developing a more *integrated* understanding, and allows students to build skills in the application of knowledge from a broad range of areas. This is critical if learners are to develop viable and successful technological solutions.

The value of such skills is recognized more broadly for a range of school curricula. Though discourse is on-going, Yates and Collins (2010) and Whitty (2010) cite growing trends in emphasis upon building students' critical skills, problem solving, and authentic, interdisciplinary, cross-subject learning. As argued by MacLellan (2005), further education has a responsibility to properly prepare college and university students for professional working environments and, if such skills are to be fostered effectively within our students, it is firstly necessary to develop them within the PSTs who will go on to facilitate their learning. Askell-Williams, Murray-Harvey and Lawson (2006) argue that strong, transferrable mental models are essential for PSTs and this is recognized as central for 21st century technology and STEM education. Arguably, this also centralizes the importance of transfer beyond the formal educational setting.

Enhancement of Transfer

As previously alluded to, an emerging body of research suggests transfer of learning between contexts is often difficult. Clancey (1995) illustrates that much of this difficulty appears linked to the constructivist tenet that, in many ways, learning is *situated* or tethered to the context in which it was first learnt. Kirsh (2009) argues that in order to break through this, learners are required to identify conceptual hints and cues that facilitate the creation of links (p.291). That being said, there are some instances in which transfer occurs more readily because contexts are seen by learners as characteristically similar. Perkins and Salomon (2012) refer to this as *low road* transfer and note that it requires far less cognitive effort to initiate. By contrast, they define *high road transfer* as comparatively challenging and manifest between contexts that are largely dissimilar. Despite Perkins and Salomon citing the development of better search strategies as integral to successful *high road transfer*, there are a number of other factors that literature has been shown to bolster positive transfer effects. Such effects are further explored below and form the basis of a framework for enhanced transfer upon which the intervention[1] for this study was designed.

Transfer: Embedding and Motivation

It is often the case that courses in both schools and universities assume that the learning will be readily applicable in a future context and do not discuss the concept of transfer with students. Indeed, even when not assumed, Thomas (1990) notes that transfer is often only discussed at the very end of the course and, moreover, that this is ineffectual. Thomas argues that transfer should explicitly permeate, and be embedded throughout the course such that students can engage with it from the onset. Likewise, and in reference to transfer in technology education, Jones (1997) argues that transfer is both complex and should be taught as part of technological practice. Having an awareness of transfer itself, however, may be insufficient. Lim and Johnson (2002) argue, as with many aspects of learning, that people must recognize the value in and be motivated to want to transfer learning. A study carried out by Kontoghiorghes (2002) examined transfer in the work environment and found that the expectation that what was learnt should be transferred was a prominent motivator.

Transfer: Authenticity, Structure & Deep Learning

Stein, Isaacs and Andrews (2004) argue that transfer is enhanced when the native learning experience is authentic in terms of students' personal meaning-making and the world beyond the course. Notably, this can be seen as broadly analogous to the concepts of *personal authenticity* and *cultural authenticity* as defined by Murphy and McCormick (1997) for problem solving in science and technology education. These notions can be seen to bridge the aforementioned requirement to *value* transfer with one of the definitive characteristics of technology education. In technology education, authenticity has been explored on a number of levels (see Snape & Fox-Turnbull, 2011) though herein, it is argued that the promotion thereof requires that three task requirements be met. First, that learning is initiated by a problem situation (rather than learning that leads to tackling a problem). Second, that this problem is genuinely problematic to students, and lastly, that the solution is characteristically technological. Though clearly relative to the solvers' experience, Frensch & Funke (1995) offer a valuable distinction in considering what satisfies the state of being *genuinely problematic*. Following an extensive review of European research, they assert that problems are either *implicit* or *explicit*. In the former, solvers have a fairly good notion of the type of thing that must be done to address the problem (such as comprehension-check exercises found at the end of a textbook chapter), whilst the latter are largely *instransparent*, which involve fluctuating problem states and complex, non-linear activity (p.18).

Alongside task authenticity, Halpern (1998) suggests that future transfer can be more easily achieved by shifting the emphasis in the original learning to account more for the procedural and structural aspects rather than the substantive content. Though this may compliment elements such as the aforementioned use of hints and cues, a balance is required to ensure this is not at the expense of learning about the associated body of content. Failure to do this may give rise to an incomplete or fragmented understanding. Both MacAulay and Cree (1999) and Halpern and Hakel (2003), argue that transfer is less likely to occur when people only gain a surface level understanding of the subject. This is because a deep understanding is necessary for them to cultivate meaningful connections or recognize cues for applying what was learnt in different contexts. Whilst on one level, this presents a degree of tension; a depth of understanding is likely to better facilitate the recognition of contextual similarities. Notably, Fleer and March (2009) discuss evidence that more authentic pedagogical approaches by teachers in science promote pupil engagement; which, in itself, is arguably a prerequisite for engendering deep learning. With regard to teachers themselves, Jones and Moreland (2004) reported that enhanced knowledge for primary school teachers engaging with technology led to explicit consideration about how they could actively help younger students improve learning transfer.

Transfer: Extension, Translation and Forward Planning

As part of an extensive review of transfer evidence, Merriam and Leahy (2005) argue that, where possible, the opportunity should be provided for university students to extend learning forward into the workplace as a way to increase positive transfer. On a similarly pragmatic level, Halpern and Hakel (2003) also advocate developing skills in taking what was learnt in one format, and translating it to another. In the context of teacher education, this shares a great deal with the development of didactic transposition (see Chevallard, 1988) where the form the information is translated into is deliberately *engineered* to fit the target context. Somewhat linked to this is also the opportunity to explicitly plan for future transfer. Gardner and Korth (1997) extend the previous notions of embedded transfer beyond the task boundaries and argue that explicit planning forces students to conceptually link that which they have learnt to a new context, and in doing so take cognizance of its opportunities, characteristics and constraints.

Analytical Focus of this Study

The intervention within this study is the preparatory course entitled "Integrating Technology," which was developed based on the existing body of research in this field specifically to enhance PSTs' skills in transfer and promote more integrated understanding. Specifically, this paper addresses the following research question: "What shifts have occurred in the thinking of pre-service teachers of technology as a result of engaging with a preparatory course designed to develop an understanding of transfer and skills in solving authentic problems?" Broadly congruent with horizontal transfer and vertical transfer, this will ultimately be explored in terms of the PSTs as: (i) developing technologists, and (ii) future teachers of technology education.

Methodology

In order to provide valuable insight to this learning and teaching intervention, a qualitative-interpretive approach was employed. This allows for a rich description of phenomena to be generated and the exploration of PSTs own social construction of their experiences. The interpretation and analysis herein was based upon responses from open-ended questionnaires, in-depth semi-structured interviews (see Appendix) and submissions of course work[2]. In addition to triangulation among three data sources, three strategies were integrated into the research design to insure permeating rigor, rather than only post-hoc assessments thereof (Morse, Barrett, Mayan, Olson & Spiers, 2002). Firstly, two stages of data gathering allowed for on-going analysis of the first to inform on and shape the second in adherence to the principle of theoretical sampling (Boeije, 2002). Moreover, this allowed for a rich description of the phenomena of interest to be developed and helped bolster the credibility of knowledge claims (Gall, Gall & Borg, 2003). Secondly, the validity and accuracy of findings and interpretations were scrutinized and refined using member checks carried out with participants during the data gathering stage and following the analysis. Where member checks were carried out, individuals' responses and the associated analyses were mapped so that they were readily identifiable by participants. Thirdly, a peer debrief with an academic staff member outside of this study was held following the analysis of data in which themes, coding and findings were scrutinized, questioned and where necessary, refined.

Data Gathering and Procedures

All ten PSTs participated in the first data gathering phase in which they completed a two-part questionnaire. The first part contained a series of open-ended questions encouraging the PSTs to consider, as fully as possible, their engagement with the Integrating Technology course, instances of challenge and changes in how they think about problem solving and their future role as a technology teacher. The second part required responses to a number of questions using Likert scales. In the second data gathering phase, in-depth individual interviews were conducted with six participants to further explore initial findings from the questionnaires. During these interviews, participants' experiences and responses to parts of the questionnaire in relation to transfer and integration were explored in greater depth. Five interviews were held face-to-face, and due to changing participant circumstances, one interview was conducted via telephone. Findings from these interviews, combined with evidence from student work, allowed the understanding of salient themes and points of interest to be deepened and corroborated within and between each source.

All six interviews were held in accordance with the criteria laid out by Gall et al. (2003), digitally recorded and lasted between 26 and 43 minutes each. To bolster face validity, it was stressed to participants throughout the interview that responses should relate directly to their experience of the intervention course only.

Recruitment of Study Participants

The target participants were first-year preservice teachers who had undertaken the Integrating Technology T1 course as part of the Bachelor of Technological Education degree programme at the University of Glasgow, Scotland. These were the only cohort of undergraduate students who had undertaken this course. PSTs were approached to request their participation, issued with a Plain Language Statement describing the study and given the opportunity to raise any questions. They were then issued with a consent form and told that their participation was entirely voluntary with no incentives offered. They were told that they could withdraw at any point without the requirement to provide a reason and that their choice to participate or not would have no bearing upon their experience as a student. Fifteen from a possible eighteen students gave consent for their submissions of work to be included, though only ten students engaged with both phases of data gathering and hence form the resultant sample for this study. The study was carried out in accordance with the British Educational Research Association Ethical Guidelines and was approved by the University of Glasgow Ethics Committee.

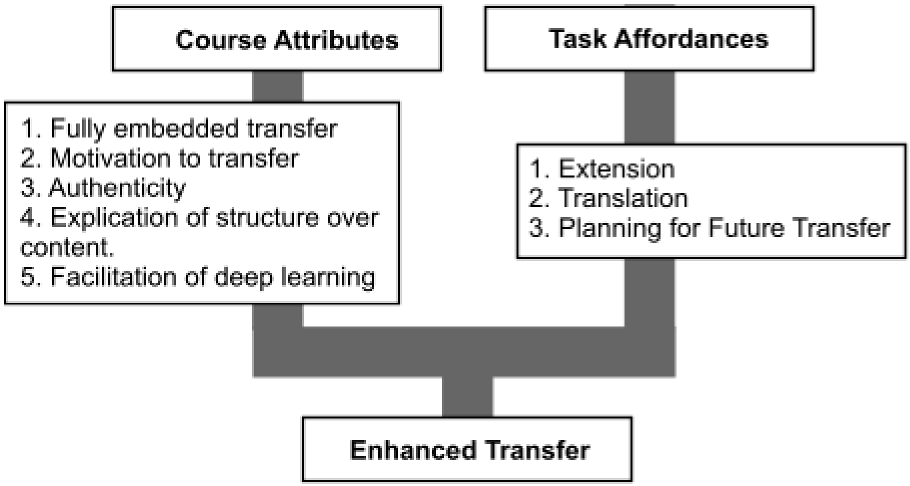
Overview of Sample

The sample consisted of six female and four male students, all of whom are referred to using pseudonyms through. The age range of the female participants was 18 to 19 years. The age range of the male participants was 18 to 20 years. All of the participants were in their first year of study of a four-year honors programme and all, bar one, entered that programme straight from high school. The Integrating Technology course dealt with the engineering systems dimensions of technology and only one participant within the sample had experience of this subject area from high school. All participants had previous experience in drawing, graphics and design subjects. None of the participants in the sample had undertaken a course that specifically explored problem solving.

Intervention and Synopsis of Student Learning Experience

In order that the intervention did seek to promote transfer skills, an original conceptual framework, shown in Figure 1, was synthesized by this author from the key findings of the literature review. This framework provided a research-informed basis for developing courses, which enhanced the likelihood of students autonomously applying the skills and content learnt in different contexts and was directly employed in the design of the Integrating Technology course. The key findings from the literature review were broken into ‘Course Attributes’ that shape and characterize the overall course, and ‘Task Affordances’ that account for opportunities that should be made available to students within task design. The framework does not dictate that all such characteristics be embedded in all facets of the course, but does allow for them to be considered and intelligently integrated on a number of levels of course development.

Figure 1 Framework for Enhanced Transfer Derived from Literature Review



The intervention developed as part of this study was based upon this model and is unique insofar as students develop their understanding of transfer at the start of the process, rather than attempting to develop it retrospectively in courses at a later stage in their degree programme. The framework incorporates elements recognized to enhance the likelihood of both horizontal and vertical transfer, as grounded in research (Perkins & Salomon, 2012; Kirsh, 2009; Thomas, 1990; Jones, 1997; Lim & Johnson, 2002; Kontoghiorghes, 2002; Stein et al., 2004; Frensch & Funke, 1995; Halpern, 1998; MacAulay & Cree, 1999; Halpern & Hakel, 2003; Gardner & Korth, 1997).

The Integrating Technology course ran during the second semester of the participants' first year course for roughly 11 weeks. It was designed to maximize the conditions for horizontal transfer in years two and three of the degree programme and engender a more integrated understanding as well as vertical transfer to contexts beyond their degree. As such, it sought to provide PSTs with skills, strategies and confidence to solve authentic technological problems; explicitly teach problem solving, contexts, and transfer; and force them to initiate search strategies in response to a complex problem. Some evidence of this type of activity is discussed by for PSTs in STEM subjects by Brears, MacIntyre and O'Sullivan (2014). In addition to general analytical tools for evaluating and decision making, two core strategies learnt as part of the course were the Woods Model of Problem Solving (Woods, 2002) and Morphological Analysis/Synthesis (Adviu, Morina & Ramadani , 2012). These served to explicate structure over content.

During the first three weeks, lecture sessions and critical reading and response tasks allowed PSTs to build up an explicit understanding of some of the difficulties with problem solving, transfer, and contexts as evidenced in the literature; this made considerations about transfer explicit from the outset (Thomas, 1990). During this time, it was explicitly explained to PSTs that the approaches learnt within this course were being developed to help them the facilitate transfer required during sections of projects within the Design and

Integrating Technology courses in years 2 and 3. Following an exploration of theory, PSTs wrote a professional practice statement exploring how they would plan for the future use of these approaches as Teachers (Gardner & Korth, 1997) and consider how to translate them into the school context. The main body of the intervention required PSTs to tackle a large-scale, explicit problem (Frensch & Funke, 1995) in mixed groups of approximately five. In this task, they had to design, to a systems level (Banks & Plant, 2013), a drinks dispenser where the volume of liquid dispensed is proportional to the amount of money a customer puts in. This was developed as it was likely to be genuinely problematic and a successfully integrated solution would require a sufficiently deep understanding of the contributory technological systems involved. Moreover, the communication of their solution would require many of the approaches students are expected to engage with in school; albeit at a more demanding level. Upon completion of the problem solving task, PSTs were given the choice to amend their practice statements. All groups completed the task successfully.

Data Preparation & Analytical Approach

Questionnaires, interviews and coursework submissions were imported into NVivo. However, rather than being transcribed as is found in most studies, interview data were coded and analyzed directly as digital waveforms. As graphical representations of the recorded audio in terms of time and amplitude, the waveforms did not allow for key word searches to be performed and responses could not be visually scanned for meaning, as with transcriptions. This approach did, however, allow the number of interpretive stages to be lowered and, as discussed by Wainwright & Russell (2010), retained closeness to the data that, on balance, offered greater analytical benefit. Given that data were auditory rather than visual, it is acknowledged that the nature of the analytical process employed here differed from that experienced with exploring transcriptions. The use of digital waveforms in this capacity was also pragmatically and technically appropriate as the study targeted a deeper, thematic level of analysis and did not seek descriptive frequencies of words and phrases.

A provisional analytical pass was used to code broad themes in the questionnaires and to describe and highlight sections of responses within the interview data. An immersive phase was then undertaken which developed through a number of stages informed by the emergence of themes of interest that arose through coding to, collapsing, merging and re-defining a series of nodes (or coding labels) within NVivo. This process was iterative and repeated until nodes were seen to appropriately reflect the data to which they were assigned. The process was continually informed through the use of descriptive, contextual and reflective memos within the software[3]. The themes, explored within the findings section, included: shifts in confidence levels and independence during problem solving; a deeper and more integrated understanding; and feeling better equipped to transfer learning and shifts in PSTs' mental models of technology teaching. Given the extended answers within both the questionnaires and interviews, both data sources were analyzed as a narrative (Riessman, 1993) and triangulated with coursework submissions using the Constant Comparative Method (Zhang & Wildemuth, 2009).

Findings

Here, the findings are presented in two successive sections. In the first, key findings from the questionnaires are presented whilst the second describes a more in-depth exploration of these through the interviews and related data sources.

Findings Obtained from Questionnaires

With responses of 'definitely agree' and 'mostly agree' (see Appendix) taken as positive, all PSTs considered themselves to be better equipped to tackle future problems as a result of engaging with this intervention. All, bar one, reported that they were more capable and confident in applying learning to complex problems than they were before. Not only do these findings suggests a strong procedural and affective benefit for an integrated understanding, but nine out of ten PSTs also reported that they gained far more knowledge than expected about the technology involved given that they did not receive lectures on this. This was corroborated through the project submissions.

Participants reported that solving explicit problems was not something generally encountered in school[4]. Differences cited by PSTs recognized the process of solving explicit problems as far less prescriptive, with little to no prior knowledge and no known answer. Two PSTs also described the problem solving as "less linear," with one arguing that whilst their experience in school "was a very linear path to problem solving, finish one aspect then move on to the next," this required continual "bouncing between planning and evaluating and researching." There was also evidence of an associated shift in the required level of independent learning. These perceived differences are arguably symptomatic of a more authentic problem frame and that although PSTs were armed with a number of strategies from the learning within the first section of the course; they had to make decisions on where and when these would be most productively employed. Nine PSTs reported limited to extensive use of the strategies given, with only one choosing not to explicitly employ these at all and simply work through the problem more reactively, drawing on his existing experience.

Additionally, there were a number of challenges reported by PSTs, which included: "trying to find a balance between research and problem solving," "working out when enough research has been done," and "constantly having to cross reference with each other in order to link up each part." There were also more specific difficulties related to the electronics and complexity of integrating systems for "money and drinks together to perform the needed task." The most prominent issues, however, were associated with initiating problem solving and strategies such as breaking up and synthesizing parts into a viable concept. In relation to this, one PST reported that:

> "This was very challenging as we began to really look into all the separate parts of the problem and define where we would go with them. As we began to do this, we found numerous directions in which we could go and trying to select the correct path for each part was difficult as there were so many parts and so many paths for each and they all had to link up at the end."

This suggests that active engagement with search strategies in response to this type of problem can quickly give rise to notable complexity. Though daunting, a number of PSTs described the role of strategies in managing these complexities and, given that no preparatory lectures were given on the substantive technology involved in the problem, it was interesting that only two PSTs cited a perceived lack of knowledge of electronics as a difficulty.

Finally, it was evident PSTs felt that they had developed their thinking about how to approach complex problems and, though challenging, that such processes could help students build confidence in problem solving. Some of these responses are illustrated in Table 1 in which participants are numbered and named in instances where they also took part in an interview.

Table 1 - PST Responses for Problem Solving & Student Confidence

Development of Thinking About Problem Solving	Bolstering Students Confidence
"This course has taught me there are different techniques to problem solving that make problem solving clearer to understand, i.e., morphological analysis and flow charts." (PST 3)	". . . it will give the [students] confidence to believe that there are ways in which to tackle problems rather than to sit and be completely stuck with a problem or issue." (PST 4)
"From now on I would use the strategies taught in this course to help me when problem solving." (PST 2)	"I would allow them to take a fresh approach to problem solving which may encourage them to try new things." (PST 6: Sam)
"This course has really made me think about different ways to approach a problem and shown many ways to split problems up and solve individually will help make the whole process easier." (PST 10: Gemma)	"I think it would benefit [students] as it makes them think of new ways to approach ideas and problems." (PST 10: Gemma)
"It has also made me think about how these strategies have been devised with how the brain functions and processes information." (PST 8)	"it will give the [students] confidence." (PST 4)

Participant comments reveal an extended and deeper understanding of problem solving for the PSTs themselves and, moreover, that it may have the potential to open up new avenues of thinking for their future students.

In summary, the questionnaires provided insight into four main areas: Firstly, the PSTs generally perceived shifts in their confidence and independence in learning. Secondly, it seems that they developed their understanding via a less linear path with challenges in judging the depth of research and integrating knowledge towards a solution. Thirdly, there was evidence that search strategies, seen as supportive for transfer, were indeed being initiated as part of this process. Lastly, that there was evidence of a perceived benefit to their future students engaging with this type of thinking.

Findings Obtained from Interviews

A number of in-depth interviews were held to explore, in greater depth, each of the four areas identified from the questionnaires. The first three of these pertain most prominently to the PSTs as developing technologists, whilst the latter begins to reveal considerations relating to them as future teachers. In the following section, these themes are explored using the interviews as a core data source with findings corroborated at key points using evidence from the questionnaires and submissions of coursework.

PSTs as Developing Technologists. This perspective considers the development of PSTs own technological skills, understanding and capabilities within the subject domain and apart from those capacities they will develop to teach this. Under this focus, three emergent themes of *confidence*, *deep and integrated understanding*, and *knowledge and use of transfer* were substantiated in greater depth through the interviews. Within the first theme, it became clear that confidence and independence were associated with aspects such as self-realization, reliance, overcoming demand, and systematic thinking. In the second, there was evidence PSTs did indeed achieve a deeper and more integrated understanding of the technology than expected and were required to interlink concepts and thinking. Lastly, the third theme revealed several cases in which transfer had become more globally autonomous moving beyond evidence of simply initiating search strategies. Each of these is now discussed.

Positive Shifts in PST Confidence and Independence. It became clear from both the questionnaires and interviews, that engaging with this form of explicit problem solving had notably increased PST's confidence, both with regard to problem solving and, as a learner in general. This was true for all bar one of those interviewed, but there were variations in the ways in which confidence grew. Gemma, for example, stated: "I feel like... I can do a lot better than I thought I could;" something echoed by others including Laura, who stated "I think my expectations of myself have changed. I think I expect a lot more of myself based on that [experience of course]." These comments suggest that, for some PSTs, engagement with this form of learning activity has the potential to alter the perceptions they hold of their own capabilities. There was also evidence of shifts on a more specific level. Gemma, for instance, felt that the deeper level of learning she achieved gave her more confidence within group decision making processes.

It was also clear that, where there was evidence of positive shifts in confidence, there were also positive shifts in associated levels of independence. The questionnaires indicated that all, bar one, PSTs responded positively, indicating that they now felt more able to make independent decisions during problem solving. Further to this, the association between increased confidence and independence was exemplified by both Kristy and Sam:

> "I think it's made me more able to go away and do things . . . individually, like. . . I don't need to be in a group or things like that. . . I can go away and say, like, systematically I need to do this, this, this, this and this, and then figure it all out by myself. . . I don't think you need as much contact time with people. . . " (Kirsty)

> "I now know that I can, even if it is just a little bit at the moment, I can go independently and learn about something new." (Sam)

Indeed, it was clear that nearly all of the PSTs interviewed had experienced a swell in confidence and an altered view on their own problem solving capabilities. Indeed, this was evident to varying degrees in all ten of the questionnaires. Among these, one PST said he felt more confident in approaching problems and another stated: "I have surprised myself as to how easily it can be understood [new and complex technological problem] when the systems are in a different context and are broken down." In her interview, Laura also stated that she "surprised" herself insofar as she did better in the intervention than she thought she would have. The exception to this lay with Richard who, on reflection, felt that it did not really add or take away from his experience as a learner. Instead, he felt the biggest boost to his confidence came with passing his first year exams and school placement. Though Richard shared a similar experience to other participants, the effect of the intervention in some areas, such as confidence, was not as profound, perhaps due to the fact that he had entered university from work, rather than from school.

What emerged from all the data, was that where a growth in confidence was reported, it stemmed largely from nature of the activity that arose in response to the explicit problem, coupled with the resultant implicit level of demand and challenge. As indicated in the questionnaires, this was experienced by PSTs most profoundly at the outset. During interviews, the problem solving task was described using as range of terms including, "challenging," "complex," "novel," "intimidating" and, at first, "confusing." Sam estimated that it perhaps took two or three weeks to establish what was working. Gemma, in both her questionnaire and interview, said that she struggled to grasp the concept that there was no single correct answer and also noted that their initial distributed approach to the problem changed to a more serial method in that face of increasing complexity:

> "To begin with, what we thought to do was. . . take the problem, split it up into what, kind of, were the main parts, and then work from there; but then we discovered that when you tried. . . once you got into, like, a main part, there were loads of other parts and we found that quite difficult. So we just kind of took each bit step-by-step and worked that out between all four of us and then moved on, and we found that easier."

For these PSTs, success in a high-demand task positively shaped their confidence. That being said, it was also noted by Laura that the risks associated with such high-demand tasks require a balance:

> ". . . it was good, but at the same time it was so intimidating. . . and if it's really. . . if you're really not comfortable with that I think it could go the exact opposite way. . . and it could completely crush your confidence and think I just can't do anything!"

This illustrates a critical consideration in planning for appropriate support and facilitation of PSTs undertaking this type of learning. Similarly, one PST noted that for students, this type of learning could "be a challenge as they would be very used to being handed information that they just need to organize." Further strategic considerations to mitigate this were voiced within interviews. Both Kirsty and Robert, for example, described building up students' experience and skills with smaller scale tasks.

Integrated Understanding, Breadth and Depth of Knowledge.

In addition to gaining confidence, there was evidence of a shift to a deeper and more integrated knowledge from problem solving. All six students agreed with this, though developed it to varying degrees. The first reason for a more integrated understanding could be linked to the non-linearity and interdependence between parts of the solution. As Sam explains:

> ". . . you can't just read stuff. . . how it works, you'd actually have to know why it works. . . . especially, sort of, like in the brief we were given. Because everything was interlinked, you needed to get to the deepest part of what you are trying to understand so they all mesh."

This implicit dependency between different systems engendered a requirement that students know enough to understand how they interact with each other. Indeed, the main project submissions confirmed that, in most instances, students did achieve a suitably detailed knowledge to successfully integrate the different systems involved in the solutions. The idea of an internal dependency and interaction was further encapsulated in a description given by Gemma of an almost snowball-like effect developing as the problem solving progressed:

> ". . . originally you would automatically think of the main things needed done, whereas now I think I would go into more depth and think, well, if I'm doin' that, I can also do this, and then I can also look into this, and then this can be brought in and that can brought in. . . "

Of note here, is that there is a balance instigated between the breadth of knowledge that has to be developed, and meeting the required depth to facilitate integration. The core mechanisms underlying this were search strategies; and three of the six students felt these had improved. It was also clear that the non-linear activity was instrumental in the development of a more integrated understanding. This was confirmed by all six interviewees. Moreover, there was evidence that strategies such as Woods' problem solving model (Woods, 2000) were instrumental in both promoting and supporting this. In his questionnaire, Stuart describes the Woods model of problem solving as something he referred to "meticulously" throughout and asserted that "it helped guide me, at the beginning, when I was initially daunted and kept me on the right track throughout."

Similar points were made by Laura, Kirsty and Gemma during the interviews and it was noted in seven of the ten questionnaires. In Laura's case, reference back to the strategies made her feel less intimidated, but Sam tended to resort to "old ways" when progress appeared slow. In contrast to this, Kirsty noted a renewed focus on strategies in times of challenge, and went on to allude to the dependency between different elements of the problem:

> "Instead of you just going: here's what I need to do, and going away and finding it out and writing it down, you're having to actually learn one thing to figure out another thing and use that again."

Arguably, the discovery of such dependencies is part of process that affords a more integrated understanding to develop.

Despite the variance noted, all interviewees agreed that the non-linear process of solving an explicit problem forced them to make connections and gave them a more integrated understanding of the technology involved. It was reported by Stuart that the experience has significantly improved his understanding of problem solving.

Transfer of Learning. All six of the students interviewed felt that they had gained skills that would help them transfer learning between subjects in the future; though this was more so for some than for others. Richard stated that there were some skills that could help and that he could now see where links might occur in subjects such as design, mechanics, electronics and math. Sam re-iterated this and also added that it would "depend on the task structure," which suggests he may still see context as a mitigating factor.

For the other four students, skills for transfer were seen to gain significantly greater traction. Gemma, Laura and Kirsty each reported that they were already using these approaches and strategies in other subjects and making connections. In Gemma's case, this was improving her understanding within sections of the design course, and when asked directly if she felt these strategies would help her transfer knowledge from other subjects into a problem solving context, Laura stated:

> "I think it has helped a lot... definitely, because I think that's one of the first things I started to think about... especially when we were writing the essay; I think that tied a lot into it."

The significance of this is twofold. Firstly, it suggests that students have altered their approaches and thinking with regard to problem solving and transfer and, secondly, the strategies are being initiated autonomously by the students. Similar evidence of examples of transfer activity was found in a number of revised practice statements. Within this, students stated: "I found myself using high road transfer which involves searching for connections between contexts" and "our electronics background was used to aid in the design of our coin mechanism." Whilst this is encouraging for future transfer within the degree programme, surprisingly, Kirsty also stated that following the intervention, she found herself consciously applying some of the strategies learnt to solve problems outside of the formal educational setting of the university. Such problems included decorating her flat, which can be seen here as an example of far transfer. Similarly, Stuart offered insight into how a combination of skills in information searching from a variety of sources and having to draw knowledge together has helped him in problems requiring far transfer. This was further confirmed in his group submission which explicitly evidenced transfer from previous learning within school and from another first year electronics course within his degree.

PSTs as Developing Teachers of Technology Education. Finally, though it was evident in the questionnaires that PTSs regarded such thinking as important to school students, further exploration revealed a range of more detailed considerations and potential shifts in future approaches as classroom teachers.

All six interviewees agreed that the completion of a professional practice statement was effective in allowing them to plan forward and consider how they might translate approaches learned into their professional workplaces. Statements made in interviews revealed students' explicit intent to: "encourage the promotion of both near and far transfer;" "introduce real life scenarios into the coursework;" "prioritize growth mind-set within lesson plans." Sam noted during his interview that this was unlike anything he had done before and said he would definitely look to build up students skills in "this type of thinking." Within one submission, he further argued for the use of "a mix of concepts" as a teacher including the Woods Problem Solving Model, Morphological Analysis and explicitly "identifying the context of a problem in order to transfer knowledge from another area and apply it." This was quite widely reflected in both the questionnaire and coursework submissions wherein one PST argued they would explicitly teach students about learning, context and transfer, and another stated:

> "Transfer is fundamental to learning, so I would include more methods of transfer and emphasis that a

> combination of different methods leads to much more successful learning."

This amounts to a significant shift in this PSTs thinking with regard to the largely linear and implicit evident with many of the participants. Richard noted that the experience will mean he seeks to give students "more freedom to explore" within problem solving task such as design. This could arguably offer benefits in terms of independent learning and creativity.

For many PSTs, the benefits to their future students of solving more explicit problems and an understanding of transfer issues appear to have been assimilated within their mental models of technology teaching. The academic practice statements that were completed by all PSTs as part of their coursework indicated that all of them described changes to their thinking in one or both of these areas. The interviews, however, revealed more emphatic examples. Gemma argued that this approach would "alter the way they [students] think" and Laura described how she was already exploring ways of using it with students when she was on her next teaching placement. Stuart this approach may be quite demanding for junior high school students, but stated that, for older students, he would "definitely be looking at every opportunity . . . to kind of, give them a flavor of explicit problem solving" and approach it by teaching both strategies and learning transfer to students.

Discussion

This study focuses on exploring the development of a more integrated understanding for PSTs of technology education by building an understanding of learning transfer within the context of authentic problem solving from the onset, rather than retrospectively. Specifically, the study addresses the question: "What shifts have occurred in the thinking of pre-service teachers of technology as a result of engaging with a preparatory course designed to develop an understanding of transfer and skills in solving authentic problems?" This was explored both in terms of PSTs as developing technologists and as future teachers of technology education. Findings from the analysis of open-ended questionnaires, in-depth interviews and course submissions highlighted positive shifts in PSTs' perceptions of: (i) their confidence, independence in learning and capabilities, (ii) the level of integration and depth of the understanding gained, (iii) their understanding of, and skills in learning transfer and, ultimately, their mental models of technology teaching.

Evidence revealed positive shifts in PST's confidence, both as problem solvers and as learners in general. While this included, inter alia, confidence in group decision-making, it was often also associated with more independent learning and a shift in PSTs self-expectations. Indeed, aspects of this are reported in a number of other studies in STEM education. Positive shifts in learner confidence, autonomy and independence are described by Schmude, Serow and Tobias (2011); Yoon, Woo, Treagust and Chandrsegaran (2012), and Temel, (2014). Dunlap (2005) describes similar findings associated with a capstone course accompanied by positive shifts in students' perceptions of their own capabilities as learners. Importantly, however, this study demonstrates that such shifts can be achieved in the early stages of students' degree programmes. In this intervention, this was the result of successfully navigating a genuinely complex and explicit problem (also reflected by Schmude et al., 2011), that demanded a less linear approach where strategies served to mitigate complexity and support learning. Arguably, the promotion and nurturing of such confidence and self-realization early on better places PSTs to develop their technological capability and expertise over time, and in a range of subject and project contexts.

Findings from this study also demonstrated that PSTs were indeed able to build up a sufficient and more integrated understanding of the technology involved as a function of the problem solving process. Although other research (Hmelo-Silver, 2004) has found merit in more academic approaches, the level of understanding achieved by PSTs in this study was sufficient and appropriate to achieve the type of integrated systems thinking previously argued by Banks and Plant (2013) to be essential for teachers of technology. Although this suggests that a yet deeper knowledge and understanding might be achieved by more traditional approaches, the gains in problem solving are regarded herein as more powerful in promoting technological thinking for the 21st century.

In this study, search strategies and an explicit knowledge of transfer featured heavily within the work of the PSTs. Findings show that PSTs feel more prepared and capable of transferring learning between subjects in the future (horizontal transfer). Though transfer has been observed within other problem-based learning studies (Brears et al., 2014; Massa, Donnelly & Hanes, 2013), this is often measured within the task of interest. Significantly, this study revealed evidence of the independent and autonomous initiation of transfer to contexts and situations beyond the task of interest. Cognizance of the assertions made by MacAulay and Cree (1999) and Halpern and Hakel (2003) would suggest that this intervention armed PSTs with a sufficiently deep level of understanding of learning transfer that they took ownership over and modified their own approach to learning. Though this study did not involve a large number of participants, autonomous transfer outside of the intervention strongly suggests that for some PSTs, a transformative shift in thinking has taken place (Mezirow, 1997). Though further research is required, the most likely explanation for autonomous initiation of transfer lies in the fact that transfer was fused explicitly with problem solving from the start of the process, rather than retrospectively or implicitly.

Finally, reflection and explicit opportunities to plan forward helped PSTs to consider their own mental models of technology teaching in view of both learning transfer and problem solving (vertical transfer). Findings revealed positive shifts in thinking for all participants in a range of areas from explicitly developing students transfer skills, to skills in solving explicit problems, pupil confidence and mind-sets. This is again indicative of changes in thinking on a transformative level (Merizow, 1997) and suggests notable potential for a *hybrid* approach, guided by the framework in Figure 1. Explicitly combining learning about learning transfer with skills development in authentic problem solving, might better equip PSTs to teach students to initiate transfer and develop a more integrated understanding between topic and subject areas. This is considered essential for learning within 21st century technology and STEM subjects.

Limitations

Rather than having a very large sample and a small number of variables, this study utilized a small sample with a large number of variables. Sample size was necessarily constrained because by the comparatively small number of PSTs involved in the Integrating Technology T1 course explored in this study. Subsequently, this paper does not claim that findings are fully generalizable. Rather, it provides important insights into the types of experiences PSTs might need to allow them to successfully deliver 21st century skills, and to help students foster a more integrated understanding between STEM subjects. Furthermore, the sample demographic was determined by the degree programme rather than by design choices within this study and it was outside the scope of the study to identify and investigate all instances of autonomous transfer following the intervention.

Future Research

A longitudinal study would allow for exploration of how PSTs' mental models shift with developing experience of problem solving and include more detailed investigation of instances of autonomous transfer between subjects in their degree programme. There is also scope to explore the ways in which this is carried forward into their work as professional teachers including use of the framework in Figure 1 as a basis for promoting this through course development. Indeed, wider use of this original framework within other studies would allow for a greater understanding of its effectiveness and facilitate possible refinement. Given that this study necessary focused on a small number of participants, exploring the extent to which these findings are reflected with subsequent or larger student groups would strengthen the consistency of findings.

Implications

Though problem-based learning is widely established within medical education, this is not so in teacher education. Though small-scale, this study contributes to the growing body of evidence about the effectiveness of such approaches in the field of STEM Education. The significant insights offered by this study suggest there could be considerable potential in fusing an understanding of learning transfer throughout contexts for solving explicit problems in technology. Use of the framework in Figure 1 to achieving transfer in the vertical sense can allow PSTs to develop specific skills associated with gaining a more integrated understanding between STEM subjects. Engineering this in the vertical direction can allow them to actively shape their mental model of teaching such that this might be subsequently developed for their future students. This approach offers notable potential in developing skills for 21st century STEM Education.

Notes

1. The intervention is a first year undergraduate course entitled "Integrating Technology"designed to foster an understanding of and skills in transfer, contexts and problem solving in a technological context. The wider context for this intervention is discussed in the methodology. Further detail about this course is available from the author upon request.
2. Student submissions analyzed within this study included: (i) individual professional practice statements in which students planned practice based on research and theory, (ii) group project submissions for the technological problem tackled, and (iii) revised practice statements upon completion of the problem solving task.
3. More information about the analytical approaches employed with the NVivo software package are available from the author on request.
4. This is regarded as symptomatic of the nature of the technology subjects experienced by the sample. Graphic Communication (Engineering Drawing) is far more prevalent, for this sample and the country, than Engineering Science based subjects. In instances where high school students engage with Design subjects, this is often still tackled in a sequential manner.

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Appendix

Summary of Questionnaire Questions & Interview Themes

Questionnaire Questions

Q1. When AND how did you make use of the theories/strategies explored in the first three lectures? If this did not happen, describe any other key strategies used and when you used them.

Q2. Please describe, as fully as you can, what you did to make the problem manageable and 'solvable'?

Q3. Please describe, as fully as you can, the three most challenging points during the problem solving process. Any and all issues associated with group working should constitute one of the three points.

Q4. Describe, as fully as you can, the main ways (if any) in which this approach to problem solving was different to problem solving you have experienced at school or in previous learning situations.

Q5. Please describe, as fully as you can, if and how this course has changed the way you think about problem solving.

Q6. This approach to problem solving was intended to develop your own in tackling complex problems. Please describe, as fully as possible, any of the skills or strategies involved in this that you think you need to develop more in the future.

Q7. Please describe, as fully as you can, whether you think this process offers any benefits and/or challenges for school [students] of technology education.

Q8. Please describe, as fully as possible, the ways in which this course has altered your image of what you will be and do as a secondary school technology teacher.

Agreement Questions

Scale: *Definitely Agree | Mostly Agree | Neither Agree Nor Disagree | Mostly Disagree | Definitely Disagree*

Q9. I feel I am better equipped to tackle future problems as a result of going through this process.

Q10. I am more able to make independent decisions when problem solving than I was before.

Q11. I am more confident and capable of searching for and applying new information and learning to a complex problem.

Q12. Given that this course focused on process over content, I have learnt more than I thought I would about the technology involved.

Interview Themes

Part A: Validation and extension questions specific to responses given by the interviewee to their questionnaire.

Part B: Common themes to all Interviewees (with indicative questions):

Theme 1: Authenticity of Problem Structuring

The effects of presenting the problem at the beginning of the course with no learning having taken place about the substantive content.

Theme 2: Transfer of Theory to Practice

The degree to which students were aware of associated theories they had learnt about coming into play during the problem solving process. How were these manifest? Did they consciously instigate these in response to challenges or specific events? Did they appear naturally?

Theme 3: Orientation, Scoping & Framing

How did the students go about orientating themselves with the problem situation? How did they generate focus in response to the problem situation?

Theme 4: Overcoming Challenge & Search Strategies

Where did challenges arise and what was done to overcome them? How and when did you decide to initiate search strategies? Was this difficult? How and when did you make use of tutor support?

Theme 5: Perceptions of Problem Solving Skills

In what ways did this approach reflect or differ from those you have experienced previously in school. How, if at all, has this altered your own approaches to solving problems? What are the key benefits this process has given you?

Theme 6: Mental Model of Teaching Technology

How has this process changed (if at all) your idea of what teaching problem solving in technology should involve? How would you cultivate similar skills in pupils? What is critical for pupils to understand?