Rethinking Computer Science Education from a Representational Approach.

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There has been a long-standing interest by science educators in learner's understandings, of which one recently developed strand is a 'representational approach' which arises out of socio-cultural perspectives. This paper reports on a brief case study in which a representational approach has been explored in the context of ICT education. Outcomes of this study involve a re-theorizing of aspects of ICT education and highlighting areas where care needs to be taken when teachers are inducted into the principles of a representational approach.

Introduction

There is a long-standing interest by science educators in learner's understanding (Hubber, Tytler & Haslam, 2010, p. 5). Certainly, an interest in constructivism since the early 1980s has galvanised an interest in learner's understandings (So, 2002) and has led to a paradigm change in science education (Tobin, 1993, p. ix), and the learning task as been increasingly cast in terms of conceptual change (Hubber, Tytler & Haslam, 2010, p. 6).

In contrast, there has been less interest on the part of Information and Communications Technology (ICT) educators with respect to learner understandings of the technology[1]. Yan and Fischer (2004) have observed that insufficient attention has been given to how people learn to use computers from the perspective of cognitive development. Hammond and Rogers (2007) have also observed the relative lack of research into children's understanding of computers and computing concepts – particularly when compared with the very large literature on teaching and learning with ICT. With respect to learner understandings, the very term "ICT" is somewhat problematic. Studies under this guise (eg Victorian Curriculum and Assessment Authority, 2008) have tended to focus on the purpose, design and context of computer-produced artifacts. The computer system is thus constructed as a tool, and

[1] Learner understandings, and an emphasis on constructivist approaches in particular, has been enormously important in computer education, particularly through the work of Seymour Papert (eg Papert, 1980) and its derivatives. In such work, use of computers in schools was not valued for its own sake, but as a means of developing knowledge in another domain, such as mathematics.

treated as a means to an end, and deep understanding of the tool itself tends not to be valued. Not that this is a bad thing – but a shift from "computers studies" or "computer science" to "ICT" in the school curriculum is not without epistemological consequences.

Albright and Walsh (2009) have considered interdisciplinary curricular theorizing. They describe disciplines as "social organized structures of knowledge production are historical and future oriented social fields with conventions and standards to evaluate and arbitrate", and a discipline as having an agenda, an attitude and a language (p. 3). Clearly, ICT and science are separate disciplines with separate agendas, attitudes and languages, although there is insufficient space in this paper to elaborate these in any detail. One would not want to contort science into a 'kind of' ICT, or ICT as a 'kind of' science. At one level, this paper presents a very short case study of employing a 'representational approach' (arising out of a sociocultural perspective of learning in science, see Prain & Tytler, 2010) in an ICT context. Moreover, that work provides a context for interdisciplinary theorizing: to reconsider both how ICT education might be conceived and to identify some issues relating to implementing a representational approach both in science and more generally.

The starting point for this discussion is the contention that a person in modern (developed) society regularly interacts with a range of the 'common-place' computing activities: word processing, e-mail, graphics, file management, virus checking, accessing pages on the Web, facebook, youtube, google or engaging in e-commerce. This parallels the reality that learners come to science education having some experiences of the world on which they can draw. Given the paucity of research into learner understandings of the technology, there is good reason to complement the "context" of work with a computer with an approach which makes the technology itself the object of study. Rather than being content with describing students as 'ICT savvy' (Christopherson, 2006) or 'digital natives' (McKenzie, 2007) and suggesting that they can (and should) 'learn all about the technology themselves' (Ellul & McGarry, 2009), attention can be focussed on such matters as what they know, how they learnt it and possibly how understanding could be improved or more efficiently developed.

An interest in what is going on 'under the hood' or 'behind the scenes' is correctly the domain of computer science. To think of learners' understandings of common place computing activities as computer science is not to suggest that the starting point should be the world of bit, bytes, data structures and the von Neumann machine, but to suggest that computer science can be reconfigured so that the 'common place activities' can be an entry point to a deeper understanding. Furthermore, it is suggested that as a representational approach provides a way of re-thinking science education practices, so too, can such approaches provide a way of re-thinking computer science education.

Representational approaches

Over the last 25 years, how science education has been understood has hardly been static. Whilst constructivism triggered paradigm shift, the passage of time has also led to a realisation that "the processes that lead to successful movement of students' thinking from a naïve to a scientific view remain elusive" (Hubber, Tytler &

Haslam, 2010, p. 6). Indeed, cognitive scientists have increasingly emphasized the importance of context, perception, feelings, embodiment, metaphor and narrative in learning. Through such a perspective, the role of representation in learning is enhanced. Rather than using the representations and canonical forms of the scientific community, learners use their own representational, cultural and cognitive resources to engage with the subject-specific representational practices of science (eg Hubber, Tytler & Haslam, 2010; Tytler, Haslam, Prain & Hubber, 2009).

How do these ideas about computer science education and science education fit together? Consider the following example of a segment presented on a morning television show, which concerns a common-place element of computing, the Internet. The segment was titled "the internet's getting full" (Seven Sunrise, 2009). To the mind of computer scientist, the internet is constructed in a particular way (almost certainly as something which is, by definition, not fillable; cloggable, perhaps, but not fillable). In contrast, to some people (the show's journalist among them, perhaps) is the conception of the internet as something fillable, and that "full" is a bad thing. Here is an example of where valuable learning could emerge, not from the starting point of network theory, but from learners using their own representational, cultural and cognitive resources to engage with the underlying science.

The premise of this paper is that this is not an isolated example, but all ICT activities include some measure of understanding the hardware and software system which makes that activity possible. There may have been a time when learners would have so little experience of computers that a transmissive approach to convey ideas of computer science 'from the ground up' was necessary, but this time has long past. The notions of learners being 'ICT savvy' and 'digital native' should provide plenty of fertile ground for using a range of cultural and cognitive resources to learn about the computer system: a new type of computer science education. As Urban-Lurain (2003) has emphasised in relation to the "Fluency with Information Technology" (FIT) initiative on which he worked,

> some argue that it is not going to be necessary to teach FITness because, as computers become ubiquitous, students will arrive at college already FIT. This argument goes back to the 1980s … However, we have found that students are not arriving at our course any more FIT than they were in the 1980s. Students have a great deal of exposure to using computers, but have little conceptual understanding (p. 69).

Literature Review

Constructivism in Computer Science Education

To portray computer science educators as doggedly treating their students as empty vessels waiting to be filled would be clearly unwarranted. Both Ben-Ari (2001) and Nordström (2002) have discussed the notion of constructivist learners as gradually taking currency in computer science education. Powers and Powers (2000, p. 1) make the point that the emphasis has tended to be on the conceptions that students construct whilst in the computing classroom, not the conceptions that they bring to the classroom door. In university-level courses, Chesñevar, Maguitman, Gonzáles and Cobo (2004) have employed such ideas in the teaching of highly abstract topics associated with the theoretical fundamentals of computing and Chen (2003) has used constructivist principles teaching computer networking. There has also been some work in field of the psychology of computer science which address school student understandings of programming and computer science concepts (eg. Ben-Ari & Yeshno, 2006; Pea, 1986; Powers & Powers, 2000).

Nothwithstanding this background, there has been little work done in relation to common place computing tasks or experiences. Amongst the limited collection are studies by Ben-Ari (1999), Yeshno and Ben-Ari (2001) and Ben-Ari (2001) who considered the mental models of word processing of academic staff in a university, and Ben-Ari and Yeshno (2006) who extended this work to school students. Hammond and Rogers (2007) considered school-level computing, interviewing 13 children in relation to questions such as ‘What is a computer?’, ‘What is logging on?’ and ‘How does a mouse work’. Young student's perspectives in explaining the ‘behaviour’ of a mechanical, autonomous robot have been studied by van Duuren and Scaife (1996) and Levy and Mioduser (2008). Kafai (2008) explored students’ conceptions of a computer virus.

There are also two large scale studies which are of interest. Firstly, Papastergiou (2005) investigated high-school students’ conceptions of the internet. There were some 340 participants from 11 Greek public high schools who participated in interviews, completed surveys and drew diagrams. The main conclusion drawn was that “high school students form simplistic, utilitarian rather than structural mental models of the Internet” (p. 356). The ImpaCT2 study carried out between 1999 and 2002 involved 60 schools in England (ImpaCT2, 2002). One component was a research task which students being asked to draw a concept map of ‘What is a computer?’, and analysis of some 2000 maps is reported in Mavers, Somekh and Restorick (2002). A subsequent study involving 6 European countries is report in Pearson and Somekh (2003). Researchers concluded that students had detailed and complex cognitive representations of networked technologies.

Representational Approaches in Computer Education

A ‘representational approach’ – that is, learners using their own representational, cultural and cognitive resources to engage with the underlying concepts – is not unknown in the computer education, but is not, as far as the author can tell, titled as such. For instance, Lloyd (1996) made a study which is interesting both in terms of methodology and findings. She studied the mental models students have of computers as expressed through both literal and figurative speech, through responses to sentence stems such as “a computer is like ...” or “programming is like ...”. The outcome of the study was that “it allowed me to ‘see’ the computer through my students’ eyes - and most alarmingly, to realise that what we were all seeing were very different things” (p. 23), though the detailed findings are potentially not relevant over a decade later.

Several authors have used approaches which we could call ‘representational’ specifically to foster student learning. Chen (2003) developed innovative teaching procedures using items such as rope, key rings and post-it notes to represent elements of a computer network and allow students to put their understanding on display. Kafai (2008) explored students’ conceptions of a computer virus, and found that that the large majority of online users have little understanding of a computer virus, and that explanations concentrated on ‘behaviour’ features of virus, not on their underlying structure. It was also found that though visual representations might work well for exploring many concepts in science learning, they did not work well in this context. Efthimiadis, Hendry, Savage-Knepshield, Tenopir and Wang (2004) also report on work which asked participants to draw: in order to identify how people conceptualise internet search engines and how they work, university students were asked to draw sketches of how they work.

The conclusion of several studies (Ben-Ari, 1999, 2002; Yeshno & Ben-Ari, 2001; Papasteriou, 2005; and Hammond & Rogers, 2007) is particularly important in relation to a representational perspective. This is the concern that in the absence of an explicitly-taught conceptual framework, students were unable to articulate their bases for working as they do. It might be inferred, therefore, that a representational approach will be found difficult in the field of common place computing. Such a perspective, it should be said, is connected with the theory of mental and conceptual models. A conceptual model is one which is invented to provide an appropriate representation of a target system; the mental model is what the user 'presently has in his/her head' about the target system (Cardinale, 1991). A consistent theme in work from this theoretical perspective is about 'engineering' the optimal performance of an individual. Whilst this approach recognises that users are not empty vessels waiting to be filled, it tends to emphasise effective 'transmission' of the conceptual or target model, and not be particularly concerned with the mental model, (though some have been, for instance a study of mental models of internet searchers by Brandt and Uden [2003]).

A representational approach stands in contrast to an 'optimal performance' perspective, being committed to learners using their own representational, cultural and cognitive resources to engage with the underlying concepts and to articulate, hard as it might be, their ways of working as they do.

Summary

In summary of this review, several things can be said. Firstly, there is no major corpus of work connecting notions of learner understandings and 'common place' computing activities. A small group of seminal works stand out: Ben-Ari (2001); Mavers, Somekh and Restorick (2002); Papasteriou (2005); Hammond and Rogers (2007); and Kafai (2008). Work by Chen (2003) and Kafai (2008) stand alone as applying representational ideas to computing concepts in the same was a science educators have applied them to science education (eg Hubber, Tytler & Haslam, 2010; Tytler, Haslam, Prain & Hubber, 2009)

From the literature review, what is clear is an emerging appreciation that learners come to computing (or related) activities with understandings, and that it is important to value these. What this presents in an opportunity to construct both a curriculum and teaching/learning activities which uses learner's understandings of common-place computing – and in particular, how they might choose represent them – as the basis of developing a deeper appreciation of aspects of computer science emerge through such activities as relevant.

A First Investigation

Having some fascination with learner's understandings in relation to common-place computing activities led to the author and a colleague devising a predict-observe-explain (POE) activity (White & Gunstone, 1992, ch. 3) to probe the understand that of a particular phenomenon in word processing (Chandler & Gesthuizen, 2010). That phenomenon was 'text wrap' and the various software settings which determine how text and graphics are positioned in relation to each other. This was thought to be possibly a challenging task, but nevertheless connected to several 'phenomena' of significance when using a computer.

The most general of these phenomena is the distinct in computer science between 'data' and 'operation'. For instance, letters and their formatting in a word processing document comprise the data, and actions such as 'copy' or 'paste' are operations. For simplicity, we might elaborate that to 'presented data' (ie the actual graphic), 'control data' (ie settings such as type of text wrap, and location of the anchor point) and 'operations' (ie dragging the graphic). The data-operation distinction is a fundamental one in computer science, but extremely general in scope. It is a little asserting that a fundamental law of the universe is that the universe is made of atoms; it is accurate and profound, but requires considerable explication and elaboration before it is useful as an explanatory framework for our day-to-day interaction in the world.

Less generally, but quite valuably, is that manipulation of on-screen objects and the positioning of each with respect to another is quite common in application software, and is found in may guises in word processors, desktop publishing, web publishing and graphics software (and many others). So an interpretation of text wrap in a range of other settings, at least some of which would be familiar to the 'ordinary' user.

This POE task was administered to students in a year 11 ICT class. The results (Chandler & Gesthuizen, 2010, p. 10) were somewhat disappointing. An analysis of 30 student responses showed that they were observant, showing an awareness that an item or process exists. A few made suggestions as to the underlying reasons for the observation, but no-one showed a knowledge of the purpose of the process and an ability to explain its use beyond that which has been first observed or with deeply reasoned arguments or productive choices.

As we reflected on this finding, there was a certain degree of disillusionment not only about the finding, but about the whole process. At best, a POE might illustrate that learners would have a viable explanation, but the extent to which that might be deep-seated (rather than a spontaneous idea) and connected with any deeper understanding is not necessarily made apparent by the task itself. Moreover, how one might use those insights to move students' thinking from to a more 'correct' view is far from clear.

An outcome of this investigation was to seek further inspiration for establishing teaching/learning experiences which both help us understand student's knowledge of some computing principles and move their thinking from a naïve to a 'correct' view. The adopting of a representation approach, whereby learners use their own representational, cultural and cognitive resources to engage with the underlying concepts is what followed, and this is presented as follows.

A Representational Approach to ICT Topics

Two trial lessons

A trial was set up with a teacher who was firstly briefed in the representational approach, taught two lessons (on different topics) by endeavoring to use this approach, and was subsequently interviewed.

The teacher who participated in the trial is qualified in both science and ICT, and would thus have reason to be interested in a representational approach in relation to both teaching areas. The class which he worked with was a group of year 11 ICT students, and on two separate occasions a lesson on cyberbullying and then on computer networking was taught using this approach. Each class was for a duration of 45 minutes.

The principles of the representational approach with which the teacher was asked to become familiar were those described by Hubber (2010b, pp. 20-21), which are summarised as follows:

- Sequencing of representational challenges involving students generating representations to actively explore and make claims about phenomena.
- Explicitly discussing representations, the process by which they are generated, their form and function and their adequacy.
- Providing strong perceptual/experiential contexts and attending to student engagement and interests through choice of task and encouraging student agency.
- Assessment through representations.

In the case of the cyberbullying lesson, students were given this introduction "in groups, represent what is cyberbullying to you – act it, dance it, perform it – and then we will reflect on what it means and the connections between the ideas that different groups have". In the space of a 45 minute lesson, one group produced a brief written research project, complete with slide show; another group concentrated on graphic material, locating some online cartoons which illustrated their perspective, and quickly drawing some others; another group created a brief drama performance. The brief for the networking lesson, and the range of presentations, were very similar. The research which the students did variously including internet searching and interviewing students in the class.

Reflections on the lessons

In reflection on these lessons, the second author was quite enthusiastic about what had taken place. Students who were sometimes hard to motivate were well motivated and creative. It was much more efficient than a chalk-and-talk lesson. However, on reflection, there was insufficient scaffolding to scope each, and the work of each group could have been more carefully devised. No "big ideas" or concepts were identified by the teacher pre-hoc, partly because the lessons were introductory and designed to be broad in scope. Student reflections were relatively broad and reflected surface-level thinking, partly because the topic was itself so broad. However, students' cultural and cognitive resources extended the topics in ways not initially envisaged by the teacher. The other-wise technical topic of networking was extended to social networking, where the purpose of the infrastructure is clear identified as the need to connect people together for various purposes. With regard to cyberbulling, of their own volition, students made "bullying" the starting point and connected that to "cyberbullying".

Discussion

On one hand, these two lessons have shown (to the teacher concerned, and to a wider audience) that otherwise dry ICT theory can be enlivened by making students responsible for researching and explicating concepts, using their own resources and presenting their ideas in ways which suit their own learning profile. This is to be celebrated. On the other hand, we might wonder whether what transpired is indicative of representational approach. On that count, and on reflection, we would need to say not. Concepts or big ideas were not well defined in the teacher's mind, there was no sequence of representational challenges, and evaluation through the representations lacked depth.

From this brief study, there are several things which have been learnt, which apply to some extent to the application of a representational approach to the ICT curriculum, but moreover to the representational approach in general:

- Firstly that it is not always transparently obvious to a teacher that there is a real and serious difference between a representational approach and a teaching/learning activity which is student-centred and allows students to present information in different ways. Given that ICT education is typically concerned with the creation of information products for an identified audience (ie 'representations') and the evaluation of these with respect to user needs, this may be a subtlety which takes time to grasp.
- Secondly, it will be easier for a teacher to construct sequence of teaching and learning activities if the 'big ideas' or concepts are articulated ahead of time. (Implications of this are discussed below.)
- Thirdly, it will be easier to build a representational approach if more time is permitted. To commence and conclude such a venture in a 45 minute lesson is teaching equivalent of a 'shot gun wedding'. That being said, it is probable that for senior classes, considerable advantage can be obtained from representational approach over a relatively short time frame.
- The forth implication concerns the approach to abstract ideas using a representational approach. 'Networking', is certainly a somewhat abstract idea. More accurately, it involves the notion of 'ostensive' and 'non-ostensive' objects (Artigue, 2002, pp. 249, 270). The computer user interacts with a familiar user interface, its mouse, menus and icons, which are the ostensive (or tangible) reality. There is a non-ostensive reality (in the case of networking) of frames, packets, protocols and bits, amongst others, which make this ostensive reality 'happen'. Using a representational approach when objects of interest are readily observed similar (for example, the observational study of invertebrates reported in Tytler, Haslam, Prain & Hubber, 2009) seems relatively straightforward, but using it when ideas are highly abstract or non-

ostensive possibly requires some explicit formulation of analogies to shape or 'seed' student's thinking (for example, the development of a unit of work on forces reported in Hubber, Tytler & Haslam, 2010). In other words, it was probably inevitable that students would latch onto conventional definitions and representations of networks rather than devise something innovative of their own which genuinely helped them unpack some of the underlying concepts.

Of all of these observations, the one which will 'make or break' the application of a representational approach to ICT education is the identification of 'big ideas' and concepts in computing. Certainly, if not concerned with the design, purpose and context of computer-product artefacts, ICT education has tended to be about the learning of a range of a catalogue of skills (see both the popular ICDL[2] and INGOT[3] programs). It is certainly our contention that 'using a computer' would be well served by becoming more 'conceptual', and it is not impossible to discern concepts relevant to 'common-place' computing. Indeed, twelve high-level conceptions of computing have been distilled from the literature (eg 'the computer as a servant') and some lower-level conceptual ideas have been suggested (Chandler, 2009), for instance:

- What it means to click; click-drag, double-click, etc
- The filing system, drive letters, folders and the idea of saving and 'save as'; absolute and relative paths
- The idea of an object and the idea of 'selecting' text or objects
- The idea of layers
- The distinction between viruses, adware and hardware/software faults

The high-level ideas are somewhat akin to a notion in science that 'the universe is continually expanding', and the lower-level ideas are somewhat akin to understanding that 'bodies not being hollow skin bags that are all 'stomach' (a reservoir in which blood, food and wastes are somehow contained)'. What is potentially tricky with ICT education is not the identification of concepts (though they are not perhaps in the lexicon of the typical ICT teacher or represented in a syllabus), but the identification of concepts of an 'order' which are useful for formulating a representational approach.

Hubber (2010a, p. 5) has defined a concept as "not simply an idea embedded in curricular documents and textbooks but consists of a set of interlinked representations and practices". Formal, "proper" computer science certainly has its set of interlinked representations and practices, for instance the diagrammatic and mathematical ways in which data structures are described (Standish, 1980). However, 'common place' computing does not have this tradition. Thus the educator seeking to develop this tradition needs to develop relevant representations and practices.

It is not beyond the realms of possibility that the fundamental, and afore-mentioned, distinction between 'data' and 'operations' a suitable 'middle order' out of which a representational approach could be built – for almost anything in 'common

[2] The International Computer Driving Licence, http://www.icdl.com
[3] An abbreviation of "International Grades - Open Technologies", http://www.theingots.org

place computing'. Learners could be asked to explore questions such as: how would you represent the data 'here'? What are the operations applicable? How does it relate to the data 'here'? In what ways is it similar or different to data in other situations. Such questions are fundamental to computer science, but it is the application of them to common-place circumstances through a representational approach which would be both novel and powerful.

Conclusion

This paper has presented a brief case study of employing a 'representational approach' in an ICT context. Some possibilities for how ICT might be reconceived have been discussed, including an emphasis on 'understanding' and 'common place computing'. This involves re-theorizing how computer science might be conceived for both non-specialist and younger learners. A representational approach, arising out of a sociocultural perspective of learning, can both contribute to this re-theorizing and provide a viable pedagogical framework for realizing this.

Furthermore, the use of a representational approach in a non-science teaching setting has highlighted areas where care should be taken when teachers are inducted into this approach.

References

Albright, J. & Walsh, C. S. (2010, December). Multiliteracies as transdisciplinary curriculum practice. Paper presented at the Australian Association for Research in Education Conference, Canberra, Australia.

Artigue, M. (2002). Learning mathematics in a CAS environment: the genesis of a reflection about instrumentation and the dialectics between technical and conceptual work. *International Journal of Computers for Mathematical Learning, 7*, 245-274.

Ben-Ari, M. (1999). *Bricolage forever!* In proceedings of the Eleventh Workshop of the Psychology of Computer Programming Interest Group, Leeds, UK, pp. 53-57. http://www.ppig.org/papers/11th-benari.pdf

Ben-Ari, M. (2001). Constructivism in computer science education. *Journal of Computers in Mathematics and Science Teaching, 20*(1), 45-73.

Ben-Ari, M. (2002). *From Theory to Experiment to Practice in CS Education*. Paper presented at the 2nd Annual Finnish/Baltic Sea Conference on Computer Science Education, Koli, Finland.

Ben-Ari, M., & Yeshno, T. (2006). Conceptual models of software artifacts. *Interacting with Computers, 18*(6), 1336-1350.

Brandt, D. S, & Uden, L. (2003) Insight into mental models of novice Internet searchers: Adaptation of Task Knowledge Structures. *Communications of the ACM, 46*(7), 133-136.

Cardinale, L.A. (1991) Conceptual models and user interaction with computers. *Computers in Human Behavior, 7*, pp. 163-169.

Chandler, P. D. (2009, December). Learner's conceptions of 'common place' computing: approaches and possibilities. Paper presented at the Australian Association for Research in Education Conference, Canberra, Australia.

Chandler, P. D. & Gesthuizen, R. J. (2010, April). *Learner's conceptions of 'common place' computing activities: a case in word processing*. Paper presented at the Australian Computers in Education Conference, Melbourne, Australia.

Chen, C. (2003). A constructivist approach to teaching: implications in teaching computer networking. *Information Technology, Learning and Performance Journal, 21*(2), 17-27.

Chesñevar, C., Maguitman, A., Gonzáles, M., and Cobo, M. (2004). Teaching fundamentals of computing theory: a constructivist approach. *Journal of Computer Science and Technology, 4*(2), 91-97.

Christopherson, P. (2006). From the VCAA Corner. *INFONET (The Journal of the Victorian Information Technology Teachers' Association), 16(*2), pp. 2-3

Efthimiadis, E. N., Hendry, D. G., Savage-Knepshield, P., Tenopir, C. & Wang, P. (2004). *Mental models of information retrieval systems*. Paper presented at the Annual Meeting of the American Society for Information Science and Technology, Providence, Rhode Island.

Ellul, R., & McGarry, P. (2009, Nov). *In their hands: student learning in Victora's netbook trial*, Victorian Information Technology Teachers' Association (VITTA) conference.

Hammond, M., & Rogers, P. (2007). An investigation of children's conceptualisation of computers and how they work. *Education and Information Technologies, 12*(1), 3-15.

Hubber, P. (2010a). Principles for a Representations focused Pedagogy. Materials for the Switched on Secondary Science Program – Module 1 "Understanding science". Department of Education and Early Childhood Development / Deakin University.

Hubber, P. (2010b). Principles for a Representations focused Pedagogy. Materials for the Switched on Secondary Science Program – Module 2 "Pedagogical approaches to teaching science". Department of Education and Early Childhood Development / Deakin University.

Hubber, P., Tytler, R., & Haslam, F. (2010). Teaching and learning about force with a representational focus: pedagogy and teacher change. *Research in Science Education*, 40, 5-28.

ImpaCT2 (2002). *Pupils' and teachers' perceptions of ICT in the home, school and community*. BECTA, Coventry, UK. Available from http://www.bnecta.org.uk/research/impact2

Kafai, Y. B. (2008). Understanding virtual epidemics: children's folk conceptions of a computer virus. *Journal of Science and Educational Technology, 17*, 523-529.

Levy, S. T., & Mioduser, D. (2008). Does it "want" or "was it programmed to …"? Kindergarten children's explanations of an autonomous robot's adaptive functioning. *International Journal of Technology and Design Education, 18*, 337-359.

Lloyd, M. (1996). Decoding devices: the analysis of mental models in a computer classroom. *Australian Educational Computing, 11*(2), 4-9.

Mavers, D., Somekh, B., & Restorick, J. (2002). Interpreting the externalised images of pupils' conceptions of ICT: methods for the analysis of concept maps. *Computers and Education*, 38, 187-207.

McKenzie, J. (2007, November). Digital Nativism, Digital Delusions, and Digital Deprivation. *From Now On, 17*(2). Available from http://fno.org/nov07/nativism.html

Nordström, B. (2002, January). *Constructivism. A computing science perspective*. Paper presented at the meeting on Foundations and the Ontological Quest in the Pontifical Lateran University, Vatican City.

Papastergiou, M. (2005). Students' mental models of the internet and their didactical exploitation in informatics education. *Education and Information Technologies, 10*(4), 341-360.

Papert, S. (1980). Mindstorms. Children, computers and powerful ideas. Brighton, Sussex, UK: The Harvester Press.

Pea, R. D. (1986). Language-independent conceptual “bugs” in novice programming. *Journal of Educational Computing Research, 2*(1), 25-36.

Pearson, M., & Somekh, B. (2003). Concept-mapping as a research tool: a study of primary children’s representations of information and communications technology (ICT). *Education and Information Technologies, 8(1), 5-22*.

Powers, K. D., & Powers, D. T. (2000, Nov). *Constructivist Implications of Preconceptions in Computing*, Proceedings of ISECON '00 (Annual Conference for Information Systems Educators). Available from http://isedj.org/isecon/2000/408/ISECON.2000.Powers.txt

Prain, V. & Tytler, R. (2010, July). Understanding how and why constructing representations supports learning in science: A theory of Representational Construction Affordances. Paper presented at the Australasian Science Education Research Association Conference, Newcastle, NSW.

Seven Sunrise (2009). *My internet’s full mummy*. http://au.lifestyle.yahoo.com/b/sunrise/24895/my-internets-full-mummy [Accessed April 28, 2009]

So, W. W-M. (2002, June). Constructivist Teaching in Primary Science, *Asia-Pacific Forum on Science Learning and Teaching, 3*(1). Available from http://www.ied.edu.hk/apfslt/v3_issue1/sowm/index.htm

Standish, T. A. (1980). Data structure techniques. Reading, Massachusetts: Addison-Wesley.

Tobin, K. (1993). Referents for making sense of science teaching. *International Journal of Science Education*, 15(3), 241-254.

Tytler, R., Haslam, F., Prain, V., & Hubber, P. (2009). An explicit representational focus for teaching and learning about animals in the environment. *Teaching Science, 55*(4), 21-27.

Urban-Lurain, M. (2003). *Fluency with information technology: the computer science perspective*. In Y. Zhao, “What should teachers know about technology: perspectives and practices”, Information Age Publishing, Greenwich, CT.

van Duuren, M., & Scaife, M. (1996). “Because a robot’s brain hasn’t got a brain, it just controls itself” – children’s attributions of brain related behaviour to intelligent artefacts. *European Journal of Psychology of Education, 11*(4), 365-376.

Victorian Curriculum and Assessment Authority. (2008). *Victorian Essential Learning Standards (VELS): Information and Communications Technology*

Domain. http://vels.vcaa.vic.edu.au/essential/interdisciplinary/ICT/ [viewed 14 July 2009].

White, R., & Gunstone, R. (1992). *Probing Understanding*. London: The Falmer Press.

Yan, Z., & Fischer, K. W. (2004). How children and adults learn to use computers: a developmental approach. *New Directions for Child and Adolescent Development, 105*, 41-61.

Yeshno, T., and Ben-Ari, M. (2001). *Salvation for bricoleurs*. In proceedings of the Thirteenth Workshop of the Psychology of Computer Programming Interest Group, Bournemouth, UK, pp. 225-235. http://www.ppig.org/papers/13th-yeshno.pdf

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