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# Technology and teaching thinking

## Why a dialogic approach is needed for the twenty-first century

*Rupert Wegerif*

UNIVERSITY OF EXETER, UK

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### Introduction

It is common to think of technology as a tool system where a tool is something used by people to get things done. So I might use a hammer to fix a loose nail in a fence. The ontological grammar behind this common sense view is that of a *subject* (me) using a *tool* (the hammer) to achieve an *objective* (fixing the fence). This ontology implies that the tools we use make no real difference to who we are and to the objectives we set ourselves. This common sense understanding of what a tool is lies behind the claim that technology in education is just about how we deliver educational goals and should not be thought of as any more than that (Clark, 1994).

An alternative view is that the use of tools changes who we are and what our educational objectives should be. A person with a hammer is likely to be looking for nails, or things that can be hit with the hammer, and might not notice other features of the environment. A person equipped with a smart mobile device and Internet connection acts differently and thinks differently from a person without such tools. On this view new communications technology is not just seen as a means to deliver educational goals, but as something that ought to be taken into account in shaping those goals (Swan et al., 2008). A prominent example of this view is the Partnership for 21st Century Skills ([www.p21.org](http://www.p21.org)), a group of educationalists and leading new technology companies lobbying the teaching and assessment of skills associated with the use of new technology. Here the tools – new digital technologies – have become an objective of education as well as being a means to achieve educational objectives. Marshall McLuhan's famous dictum: 'the medium is the message' dramatizes this very different view of the role of technology in education (McLuhan, 1962, 1964).

The same two alternative ontologies or alternative grammars for organizing reality, apply to the issue of the relationship between thinking and technology. Is technology just the product of thinking or does it shape thinking from within? I am going to argue that there are good reasons, supported by compelling empirical evidence, to claim that technology shapes thinking from within. In order to make that argument I start with brief discussions of how we should use the words 'thinking' and 'technology'.

## Thinking?

The word 'thinking' in the phrase 'teaching thinking' does not just refer to any thinking but more precisely to the kind of thinking that we value and want to see more of. Lauren Resnick once asked many people in the teaching thinking movement what they meant by 'Higher Order Thinking', which I think means the same as 'good thinking' or the kind of thinking that they wanted to promote in education. The answer was that it cannot be defined in advance but that you can recognize it when you see it. Higher Order Thinking is complex, involves competing sets of criteria (i.e. multiple 'frames' or voices, not just one), and the results are often surprising while being always insightful in that they make better sense of the initial problem or question. (Resnick, 1987).

Resnick's list of the characteristics of 'Higher Order Thinking' reflected the dominant assumption in psychology that thinking is an attribute of individuals. However, it is noticeable that every criterion in her list could also refer to the kind of thinking that we experience in dialogues. Resnick stresses the uncertainty involved in good thinking, that it is not 'algorithmic' and involves more than one perspective. I interpret this as meaning that it is 'dialogic' as opposed to 'monologic'. Dialogic simply means that more than one voice or perspective is implicated in the meaning and that there is no prospect of a simple reduction to a single perspective or single voice (for an extended discussion and definition of the term 'dialogic' see Wegerif, 2013, Chapter 2). Dialogic thinking is a property of dialogues and although individuals engage in dialogic thinking or internal dialogue, dialogues are more commonly associated with groups. So should we think about thinking as primarily an activity of individuals or as an activity of groups and collectives?

If we define thinking in terms of outcomes such as new scientific or artistic products then it has always been clear that it has a distributed and collective dimension (Surowiecki, 2004). There has been disagreement, however, on the location of the process of thinking. It is still commonly argued that only individual brains can really 'think' but when those brains communicate together and share their thinking, often mediated by technology, then there are group thinking effects which can enhance or augment individual thinking. This is probably the default assumption of most neuro-cognitive psychology. The dialogic alternative view is that thinking is social in its origins and remains social or dialogic in its essential nature even when it is apparently 'internalised' or 'appropriated' by individuals (Fernyhough, 1996: Gallagher, 2012).

The separate reality of group thinking has recently been a focus of experimental activity. Just as some individuals do better than others on a range of thinking tasks so some groups do better than other groups at solving a range of different kinds of problems (Woolley et al., 2010). This research has found that the effectiveness of group thinking correlates more with the presence of social sensitivity than with the individual cognitive abilities of group members. Social sensitivity is about an ability to understand how other people feel and was measured in this research by asking participants to identify feelings just by looking at pictures of other people's eyes. Similarly research, research that I have been involved with, suggests that individuals can learn to do better on Raven's reasoning tests after participating in groups that are taught how to talk together in a more productive way (Wegerif, Mercer and Dawes, 1999). This suggests the working hypothesis that the process of thinking is dialogic in form and has both a social external and visible aspect as well as an individual internal and invisible aspect.

By the term 'thinking', as used in the phrase 'teaching thinking', I am not referring to all forms of cognition but to the surprising and complex chains of insight that can arise between voices and perspectives in dialogue, whether that dialogue is external and visible, internal and invisible, or, more commonly, a combination of the two.

## Technology?

The word technology is most commonly used to refer to very tangible machines that enhance human physical abilities. Aeroplanes, fridges and computers are all obviously forms of technology in everyday spoken English. However the Greek word *techné*, from which technology derives, referred to the techniques used in the material arts such as weaving or pottery. By etymology technology refers not just to physical artifacts like fridges, but also to the language and cultural practices that make these objects possible. A fridge, for example, is not just a stand alone machine but is part of a larger network that includes scientific theories about chemical heat exchange, factory plans, electricity supply, the conversations of designers and repairers and much more (Latour, 2005).

The Internet with its complex combination of protocols, languages, servers and fibre optic cables is obviously a technology or, perhaps, a nexus of technologies. As a medium of communication, it does not only have an 'outside' but also an 'inside'. By the term 'inside' I am referring to the experience that arises from participating in the dialogues and exchanges that the Internet makes possible.

Written language is now widely referred to as a technology (Preiss and Sternberg, 2005) but what about spoken language? Written language is always an artefact, it is always found in a constructed material form, but speech seems to come more naturally to us, almost as naturally as the bodies which we use to make expressions with our faces and gestures with our hands. Just as it would be odd to refer to our bodies as a 'technology' it seems odd to refer to everyday oracy as a technology. However, the idea that all words are cognitive tools and language is 'the tool of tools' is widely shared amongst researchers in a Vygotskian tradition (Wells, 1999; Mercer and Littleton, 2007; Kozulin, 1986).

When we use the term technology in schools now, it is only to refer to new digital tools and new digital media. Whiteboards, marker pens, pencils, exercise books and so on are not thought of as technology because they have become naturalized. In harmony with this normal usage the focus of this chapter is on new communications technologies, especially the Internet and related digital tools. However, I also follow Vygotsky in extending the idea of technology to all means of communication but I only do so in order to be able to compare the impact of earlier communications technologies with digital technology. I follow Simondon in understanding that technology apparently has two sides, a phenomenological side as well as an apparently objective or material side.

## The 'thinking' part of 'teaching thinking' changes over time

Few people should be surprised to learn that technology change impacts on the kind of thinking that we value. As technology takes over once prized aspects of cognition such as memory and formal logic, other aspects such as social sensitivity and creativity, inevitably move forward in our estimation. But what is perhaps more surprising is that there is also evidence that changing technology use impacts on how we actually think. 'The Flynn effect' is the label given to empirical evidence that how most people think has changed significantly over the last hundred years. There is good reason to think that this change in thinking has been brought about by changing technology in the form of education and literacy practices.

James Flynn, looked back at records of raw scores of IQ tests before they were standardized. This data shows, for example, that, in just 30 years between 1952 and 1982, the average IQ of 18 year olds in the Netherlands went up by over 20 points. (Flynn, 2009) Similar rises in IQ have been found throughout the world since the beginning of the use of such tests about one hundred years ago.

So what caused this rapid rise in IQ test scores? Many competing explanations have been put forward but most commentators give a prominent role to increased formal schooling and often related changes in the use of communications technologies (Neisser, 1998; Greenfield, 2009). In his book *What is Intelligence?* Flynn looks for an explanation in the data gathered by Luria and Vygotsky in Uzbekistan reflecting the differences between the thinking of schooled literate people and non-schooled non-literate people. He quotes this example of an interview with a non-literate (Flynn, 2009, p. 27):

White bears and Novaya Zemlya (Luria, 1976, pp. 108–109)

Q: All bears are white where there is always snow; in Novaya Zemlya there is always snow; what color are the bears there?

A: I have seen only black bears and I do not talk of what I have not seen.

Q: What do my words imply?

A: If a person has not been there he cannot say anything on the basis of words. If a man was 60 or 80 and had seen a white bear there and told me about it, he could be believed.

Flynn writes in commentary on this and other extracts from Luria, that ‘If the everyday world is your cognitive home, it is not natural to detach abstractions and logic and the hypothetical from their concrete referents’ (Flynn, 2009, p 24). His point is that the unschooled thinking is not worse than schooled thinking, it is a product of a different life-world. Non-literate thinking is based on experience and is often more useful in the non-literate life-world than thinking mediated by abstract concepts. However in the modern world much experience is already mediated by symbolic abstractions. Where the Uzbek peasants interviewed by Luria lived by planting, digging, herding and hunting many modern people have to earn their living by manipulating symbols in offices.

### **From oracy to print literacy: communication technology on the inside of thinking**

When Walter Ong read the Luria data he interpreted it in terms of a contrast between oral ways of thinking and literate ways of thinking (Ong, 1982, p. 50; Lieberman, 2008). In oral cultures, he claimed, thinking is situated in contexts and in relationships. The meanings of words cannot be removed from those situations and considered in abstraction. In many cases this is quite literally true since oral people are aware of language only as audible utterances from which it is not always possible to extract separate words. Those who have been literate from early childhood tend to be able to see words as well as hear them even as they listen to them. This makes it much easier for literates to separate out words and consider their meanings in abstraction from specific contexts of speech between people (Dehaene, 2009).

In the *Phaedrus* Socrates argued that logos (reason) is never abstract but is always reasoning in the context of relationships. Inspired by Socrates, Bakhtin coined the term ‘dialogic’ as a contrast to more formal abstract logics. These formal abstract logics and models of reason of every kind are only possible because of literacy. Plato’s famous invention of ‘dialectic’ for example, is a product of writing down dialogues after the event and focusing only on one successful strand of reasoning to the exclusion of all the contingent pathways and uncertainty of a living dialogue (Nikulin, 2010). Dialogic is different from written down argument because it always implies the creative co-presence of multiple voices. Bakhtin expands on Socrates’ initial argument:

The idea begins to live, that is, to take shape, to develop, to find and renew its verbal expression, to give birth to new ideas, only when it enters into genuine dialogic relationships with other ideas, with the ideas of *others*. Human thought becomes genuine thought, that is, an idea, only under conditions of living contact with another and alien thought, a thought embodied in someone else's voice, that is, in someone else's consciousness expressed in discourse. At that point of contact between voices-consciousnesses the idea is born and lives.

*(Bakhtin, 1984, p. 88)*

Socrates' critique of the danger of monologism that is inherent in writing appears especially relevant to us now because of the new kind of writing-thinking that is afforded by the Internet. Oracy supports a dialogic view of thinking as situated in contexts where language is used within relationships. This is different from the kind of unsituated abstract logical kind of thinking that has become privileged by the combination of print literacy with modern schooling and that is embodied in the similarities and difference component of a standard IQ test.

The Internet, which is rapidly replacing print as what could be called 'the dominant medium of communication' (Poster, 1995), offers a return to some of the dialogic affordances of oracy. The ideal of truth as an unsituated representation makes sense when all we have are books, but on the Internet there is always also the potential of a living relationships with multiple voices and there is no way of stepping outside of this dialogue into a position of certainty. That is why Wikipedia is more changeable and uncertain than traditional print encyclopedias whilst being both more accurate and more up-to-date (Giles, 2005). Anyone using Wikipedia needs to learn how to check sources and therefore how to participate, if only in a small way, in producing knowledge as well as passively consuming the knowledge that has already been produced and written down by others.

## Teaching thinking for the twenty-first century

IQ tests were designed at the beginning of the twentieth century to measure a highly valued kind of thinking correlated with success in education. The specific contents of IQ tests, the similarities test for example, suggest that one aspect of this kind of thinking is mediation by abstract concepts understood as universal and unsituated. Walter Ong implies that this kind of thinking is related to print literacy. The Flynn effect suggests that throughout the twentieth century people became increasingly habituated to a specific model of 'good thinking' linked a specific affordance of print-literacy. They did not just value this way of thinking more, they also became much better at doing it.

But now we are in the twenty-first century and our dominant means of communication is in the process of change from print to the Internet. Is this change in the way that we communicate leading to changes in the kind of thinking that we value and that we want to teach? Is it also leading to actual changes in the way that we think?

## Ways of relating technology to teaching thinking

So far I have used a discussion of the implications of the Flynn effect to argue that technology use, especially widely used forms of communications technology, influences not only what kind of thinking is valued but also how people actually think. Using ideas from Socrates, Ong and Bakhtin I have focused on the significance of moving from oracy to print literacy (plus formal schooling). But of course the impact of technology is more complex and nuanced than

this simple story implies. The highest gains in the Flynn effect are found in the test of which words are similar or different and in non-verbal reasoning using Raven's progressive matrices (puzzles requiring visual-spatial thinking) but there has been only a small gain in the vocabulary component. While expanding education remains a likely explanation (Ceci, 1991) Greenfield also relates specific changes in visual reasoning to the spread of TV and, more recently, video games (Greenfield, 2009). My hypothesis is that moving to the dominance of multi-modal and dialogic communication via the Internet may have cognitive consequences that are just as great as those found in the shift from oracy to literacy (Wegerif, 2013). One of these consequences is the increasing demand for dialogic thinking skills. But, of course, the technology itself does not determine these changes, what determines them is the way that the technology is used.

When I reviewed this relationship between technology and teaching thinking for Nesta FutureLab in 2003 (Wegerif, 2003) I referred to three main ways of conceptualizing this relationship: technology as tutor, technology as tool and technology as medium for collaborative thinking. Now I would like to elaborate on that same schema, expanding it a little:

- 1 Technology as a tutor of thinking
- 2 Technology as a tool for thinking (instrumentalization)
- 3 Technology as an environment for developing thinking (constructionism and epistemic frames)
- 4 Technology as opening, expanding and resourcing dialogic spaces.

These four conceptualizations are not mutually exclusive. In particular I will go on to show how the fourth one, a dialogic conceptualization of the role of technology in teaching and learning thinking, can provide a useful umbrella framework for understanding the other three.

### **Technology as a direct tutor of thinking**

If the role of a teacher of thinking is understood as inducting students into dialogue then technology can and does play this role. Even asking simple open questions like 'why?' can be an effective stimulus to reflective dialogic thought. Many tutorial systems incorporate such open prompts for reflection. In one project where the focus was on students talking together with technology I designed what I called a 'talking bug' to sit on top of a physics simulation on the screen. Whenever the students, working together, tried to run an experiment, the bug would intervene and ask them to make a prediction about what would happen. After the experiment was done the bug would re-appear to ask if their prediction was right and if so then why and if not then why not? In groups that had been given some education in how to talk together effectively (Dawes, Mercer and Wegerif, 2004) this simple direct tutoring strategy stimulated a lot of effective educational talk.

Similar approaches are in use to stimulate reflection in online Personal Learning Environments (PLEs) (Vazquez, 2013) Online 'chatterbots', agents who text chat to others as if they were people, are now commonly used in online environments for a variety of purposes. Agents whose role is to stimulate thinking in online environments are being experimented with (Soller et al., 2005).

In the EC funded Argonaut project ([www.argonaut.org/](http://www.argonaut.org/)) I worked with a multi-national team to develop indicators of the quality of discussion in online graphically mediated dialogues (see Figure 35.1). With a machine learning algorithm based on pattern matching from initially hand coded examples, we managed to accurately recognize chains of reasoning and creativity. This fed back to a display intended for moderators but also available to students. These indicators

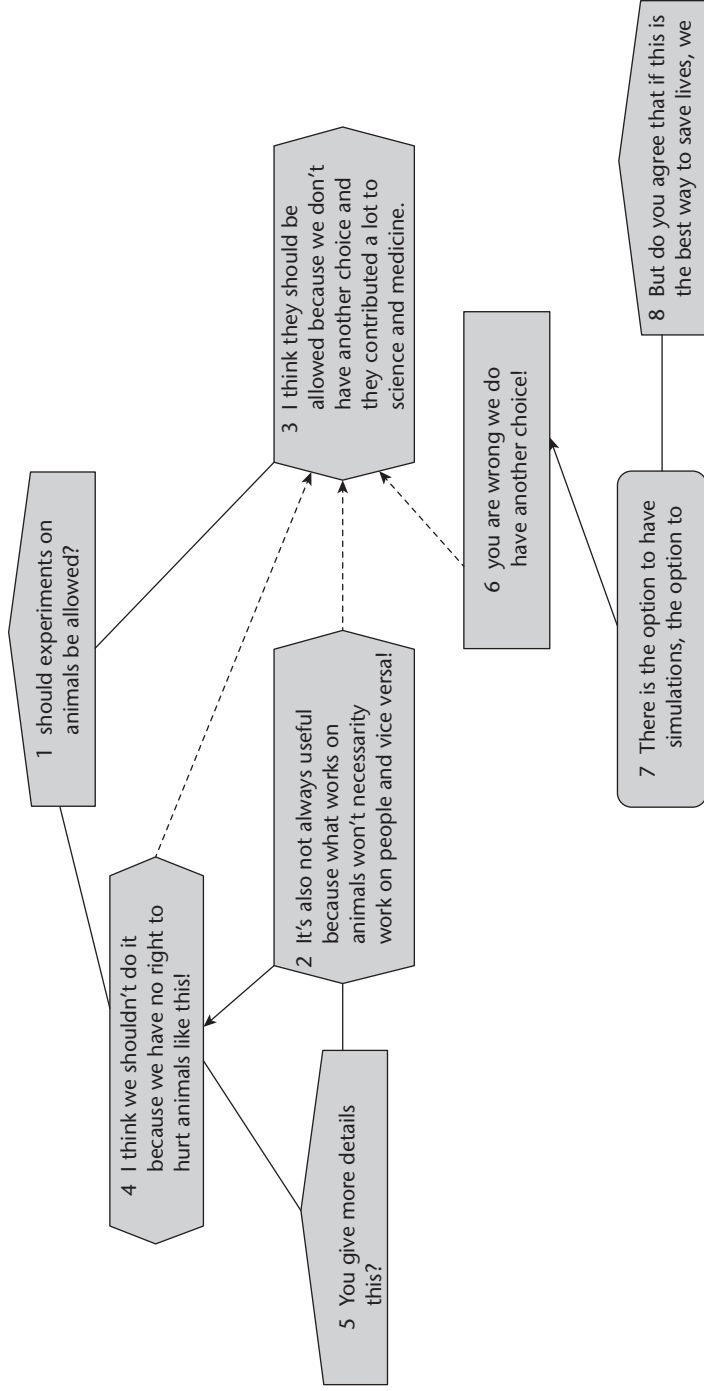


Figure 35.1 Argonaut map and user interface.

of the educational quality of dialogues could serve as a support for the thinking of moderators and students. An exciting feature of this software is that indicators of the quality of dialogue are able to evolve. Comments to moderators indicating the presence of creativity, or the lack of this, for example, can be rated for usefulness and that information fed back to inform the machine learning algorithm. By picking up and reflecting back to the group, indications of reasoning and of creativity, the technology was also teaching reasoning and creativity (Wegerif et al., 2010).

### Technology as tool for thinking (instrumentalisation)

Vygotsky argued that thinking is first found socially in the use of language and other ‘cultural tools’ and that individuals learn to think through internalizing the use of these cultural tools which then become cognitive tools or tools to think with (Vygosky, 1987). In an article provocatively titled ‘We have met technology and it is us’ Michael Cole and Jan Derry illustrate Vygotsky’s thesis with the example of the use of the Abacus for arithmetic. The Abacus does not only help students do calculations it also changes the way in which they think arithmetically. The differences in the mental arithmetic of skilled abacus users in comparison with students who do not use an abacus can be picked out by differences found in fMRI brain scans (Cole and Derry, 2005).

‘Instrumentalization theory’ is a more recent version of this Vygotskian view stemming from a unique French tradition and currently found mostly in mathematics education. Simondon (1989) distinguished between the tool in itself and the ‘instrument’, which is the tool as it used by people to shape attention and make distinctions. The process by which the tool becomes an instrument is called *instrumental genesis*. Instrumental genesis changes the tool at the same time as it changes the person using the tool. In mathematics several studies have explored how the instrumentalization process, forms the way in which students see problems and shapes the way that they think (e.g. Leung, Chan and Lopez-Real, 2006).

Various ways of visually mapping thinking are widely used in education for thinking (Okado et al., 2008; Hyerle, 2009). Instrumentation theory offers one way of approaching an understanding of how maps help support thinking. Learning to work with the maps, students learn to see key structures of thought more clearly, such as figure-ground (Hyerle’s ‘circle map’) and causality (Hyerle’s ‘flow map’). In the multi-national Metafora EU project I worked with others to develop a visual language to support the complex essential twenty-first century competence of learning to learn together (L2L2). This language took the form of icons in a map that enabled students to reflect on the process and component parts of L2L2.

The visual language was developed through extensive literature review and design workshops. Table 35.1 summarizes the six categories of the visual language. The categories of ‘Activity Stage’, ‘Activity Process’, ‘Resource’ and ‘Connector’ are used to represent the dimension of task management. The categories of ‘Role’ and ‘Attitude’ are used to represent the dimension of social relationships.

The use of this visual language in the planning and reflection space of the Metafora system is illustrated in Figure 35.2. This is a snap-shot of part of a ‘map’ developed by a group of secondary students working on a mathematics challenge using a mathematical micro-world. The L2L2 visual language map integrated with the micro-worlds that they used to help work on the problems. It is interesting to note the icons that represent the micro-world they are using and even different states of that micro-world. Each of these icons act as dynamic portals, opening up the micro-world when clicked.

Simply by looking through the options available to them students got ideas on how to proceed with their shared enquiries. Thinking together about how to locate icons like ‘explore’, ‘build model’ and ‘test’, helped students to understand the process of shared enquiry. Pre-post testing



Table 35.1 Categories of icons in the visual language for L2L2 (Metafora)

Component	Explanation	Visual
Activity stage	Key stages of dialogic enquiry-based learning process, e.g. Explore, Reflect on process	
Activity process	Key activities to concretize the process of each activity stage, e.g. Report, Anticipate	
Attitude	Key intersubjective orientations to specify the group attitudes during activity stage and process, characterized as colored glasses e.g. Ethical	
Role	Key roles to manage and mediate collaboration and cooperation between learners and groups, e.g. Manager, Evaluator	
Resource	Available resources for activity stages and processes, e.g. Group discussion map, Microworld artefact, etc.	
Connector	Key relationships between all the components, e.g. causal relationship, temporal relationship	

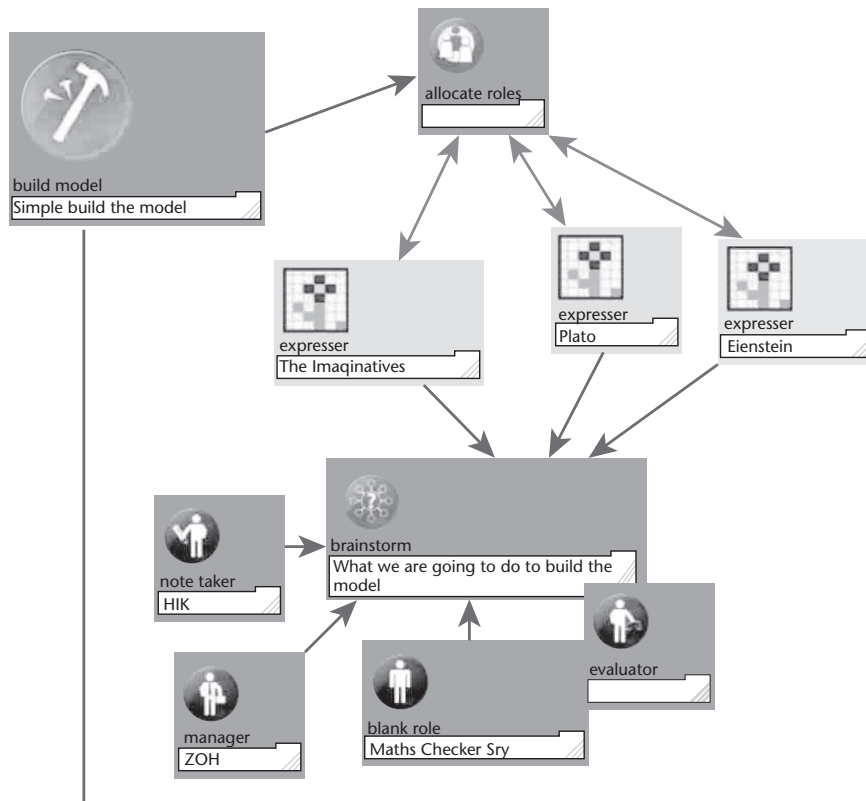


Figure 35.2 Example of a planning and reflection map

suggested that working with this tool helped students understand how to learn together more effectively with others (Yang and Wegerif, 2013). This process of learning with a dedicated tool is an example of how instrumentalisation, or converting an artifact into an instrument of thinking, can help to teach general thinking and learning skills and competences.

## Technology as an environment for thinking (constructionism and epistemic frames)

Seymour Papert, who once worked with Piaget, coined the term constructionism, which he explains as follows:

From constructivist theories of psychology we take a view of learning as a reconstruction rather than as a transmission of knowledge. Then we extend the idea of manipulative materials to the idea that learning is most effective when part of an activity the learner experiences as constructing is a meaningful product.

*(Sabelli, 2008)*

While this idea could apply to modelling with traditional materials such as pen and paper, or chalk and blackboard, it has mostly been applied to the use of new technology. Constructionism claims that students learn to think using the logic of a domain area such as mathematics, by programming simulations modelling relationships in that domain. Papert raised the exciting prospect that computer programming could mean that the sort of abstract logical thinking that many children find so difficult to learn in school, becomes easy to learn in a more experiential way simply by working and playing in a micro-world. This view lay behind the implementation of the logic programming language logo in many primary classrooms. The idea is that simply by using logo to build programmes that do things children will learn abstract logical thinking. Here the technology is not seen as a language to support reflection but more as an environment that supports understanding through building models.

Perhaps because of its origins in Piagetian theory, constructionism has tended not to focus on social interaction. However, evaluations have not indicated that the logical thinking required to program computers with logo automatically transfers to thinking in new context. In other words children can learn to use LOGO without learning more general and transferable thinking skills. For learning that can transfer it seems that reflection is needed and for reflection, peer interaction helps as does structured teaching that intentionally builds bridges between the strategies used in LOGO and logically similar strategies applied in other contexts. (Wegerif, 2003)

The combination of building models with talking and reflecting about those models, is a way forward for constructionism that we explored in the Metafora project. (Kynigos and Moustaki, 2013) Metafora included micro-worlds such as 'Expresser', referred to by icon in Figure 35.2, a micro-world designed to support students' transition from the 'specific' to the 'general' by constructing figural patterns of square tiles. However, in Metafora these micro-worlds were integrated with the visual language for planning and reflection described above and also with a further space for graphical dialogue called LASAD (similar in many ways to the Argunaut dialogue map shown in Figure 35.1 but without the moderators dashboard of awareness tools). Our idea was that discussing and reflecting would help students generalize more explicitly. Evaluative research showed many occasions where this can be seen to be happening in the interactions around the software. (Yang and Wegerif, 2013)

Epistemic games offer a similar approach to metafora in that they combine some constructionist learning principles with reflection and dialogue. David Williamson Shaffer developed the

idea of epistemic games to reflect a socio-cultural theory of education as learning a culture. It is similar to Papert's ideas in that learning occurs naturally through participation within an environment that is prestructured to reflect the rules of a knowledge area. Papert's constructionist learning environments mostly taught mathematics but Shaffer's games are broader, including learning how to be a journalist or a bio-chemist (Shaffer, 2007). The structure that is learnt can be broken down into:

- Skills: the things people within the community do
- Knowledge: the community's shared understandings
- Identity: how members of the community see themselves
- Values: the beliefs held by community members
- Epistemology: how community members make decisions and justify their choices

Shaffer calls this structure an 'epistemic frame'. With epistemic frames skills are not abstract but are linked to practice in contexts over time. In epistemic games, players learn to make connections through the cycle of action and reflection on action with peers and mentors. Epistemic games include 'Digital Zoo', where players learn physics and engineering by working as biomechanical engineers and 'Science.net' where players learn about ecology, genetics, communications technologies, and other current issues through working as journalists. This approach is relevant to the enterprise of teaching thinking because the focus of learning is on learning thinking in the situated and cultural form or acquiring 'epistemic frames' (Shaffer, 2012; Shaffer and Gee, 2012).

### Technology as expanding and resourcing dialogic space

Dialogic theory draws upon the philosophy of Bakhtin, mentioned above, as well as the findings of developmental cognitive psychology and research on classroom talk in order to argue that learning to think is about being drawn into a dialogue with multiple perspectives (Wegerif, 2013). Thinking implies seeing as if through the perspective of another which is only possible through dialogic relations with outside voices and outside perspectives. Dialogic theory agrees with Shaffer that we always see the world through a frame but rather than focusing on teaching frames the focus is on teaching how to go forward when frames clash. Richard Paul made an important distinction between teaching critical thinking in the weak sense, teaching a set of rules of good thinking, and teaching critical thinking in the strong sense, which requires engagement between different worldviews (Paul, 1994). Teaching just one 'epistemic frame' can be like teaching critical thinking in the weak sense. A dialogic approach to teaching thinking advocates learning how to see the same problem or situation from multiple frames simultaneously within the dynamic tension of a dialogue.

Dialogic theory claims that thinking is an aspect of dialogues. This gives communications technology a role on the inside of thinking. Technology enables dialogues to take on an external form and that enables more than one person or a collective to reflect on ideas. Collective thinking combines the external visible technological moment of thinking with the apparently 'internal', invisible and uniquely human moment of reflection. Technology is essential to thinking because it carries the dialogues that unite diverse voices whilst maintaining their separation. Technology also resources those dialogues with sign-tools, such as Avatars or message icons, that stand-in for voices/perspectives and allow us to invoke them and to keep them in play in a dialogue thus providing continuity. Successful dialogues in science display a dialectical (i.e. a progressive) oscillation between dialogues and artefacts such as models or 'maps' that capture and encapsulate the fruits of those dialogues in a new perspective upon which the next dialogue can build (Wegerif 2007, pp. 278–280).

For dialogic theory thinking is primarily a collective achievement and is only secondarily individual. Individuals provide a temporary space within which collective dialogues play. The collective nature of thinking can only be realized through the artefacts of culture, especially communications technology. The Internet has the potential to support a vastly expanded dialogic space by bringing more voices into productive relationship with each other and this can result in improved collective thinking. Improved collective thinking inevitably leads to improved individual thinking (Wegerif, Mercer and Dawes, 1999). On this dialogic model, teaching thinking means teaching collective thinking through changing the shared culture and through providing technological support in the form of spaces and resources.

Individuals appropriate collective thinking and participate in it through participating in dialogues. The key complex competence or '21st Century Skill' required to help individuals participate in collective thinking can be characterized as 'Learning to Learn Together' (L2L2) with digital technology. Learning and thinking with the aide of the Internet is not just working with tools it is learning and thinking together with others mediated by technology. L2L2 refers to the skills and dispositions needed to be able to listen to others and learn from them, to be both teachable and learnable, and also to be able to work together with others on more open-ended enquiry-based learning projects.

## Conclusions

The claim that technology use can shape thinking on the inside has some truth to it but it also has limitations. Technology, on its own, does not think. Just working with technology on its own does not always lead to thinking. It is in the combination of technology with reflection and dialogue that students learn to think.

The limitations of technology as tool and technology as environment models of teaching and learning thinking, point to the need for a dialogic theory. Dialogic theory combines an understanding of the role of technology with an understanding of the importance of maintaining different voices in tension. Dialogic theory is not however a replacement for all the other theories but rather, as befits a dialogic approach, it is an augmentation of them, expanding the field of debate with a new voice that does not occlude the other voices but actually allows them to speak more clearly. This new dialogic theory suggests that we learn through taking the perspectives of others and that teaching thinking is about inducting learners into dialogue and then expanding the dialogic space, which means expanding the range and the depth of perspectives that can be brought to bear on any given problem. Illustrations of how the complex competence of learning to learn together with technology could be taught were taken from recent projects especially Argonaut and Metafora. These demonstrated ways in which technological supports could be used to expand and sustain dialogic space in order to teach collective thinking in the context of understanding knowledge domain areas and solving real world problems. Although students tended to work together in classrooms with Metafora and Argonaut, their interaction was mediated by online tools so there is no reason why a similar approach to learning and teaching could not be incorporated into distance education courses.

In the emerging Internet Age our greatest challenge is teaching better collective thinking. A dialogic approach addresses this challenge with the claim that thinking is dialogue and that teaching thinking is using technology and pedagogy to both expand and deepen the space of dialogue.

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