NETWORKING METHODOLOGIES: ISSUES ARISING FROM A RESEARCH STUDY EMPLOYING A MULTI-MEDIA ARTEFACT

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This paper focuses on the methodological matters arising from using a multi-media artefact in an empirical study of student teacher collaborative mathematical problem solving. The use of this artefact in post-task stimulated recall interviews allowed two distinct methods of collecting data to be 'networked'. Issues raised by this 'networking of methodologies' include: how an artefact can enable the networking of methodologies; what a methodology is and its relationship with 'theory'; and a consideration of the work of past CERME 'theory group' participants' views on theories and methodologies.

Key-words: methodology, networking, think-aloud protocols, task-based interviews, stimulated recall.

INTRODUCTION

In the course of investigating student teacher collaborative mathematical problem solving we employed a specific multi-media artefact (the *Livescribe* pen, described later). The use of this artefact in post-task stimulated recall interviews suggested that two apparently distinct methods of collecting data on collaborative problem solving, think-aloud protocols (Ericsson & Simon, 1993) and task-based interviews (Goldin, 1997), could be 'networked'. In this paper we foreground methodological aspects of the investigation to explore issues related to networking theories.

This paper is structured as follows. We begin by describing think-aloud protocols and task-based interviews approaches. We then consider stimulated recall methodologies and *Livescribe* pens. We then outline our investigation of collaborative problem solving, to provide readers with the context of the research and a rationale for the approach we adopted. This is followed by an outline of past CERME 'theory group' participants, Radford (2008) and Artigue, Bosch & Gascón (2011), with particular regard to the place of methodology in theoretical frameworks. The paper ends with a discussion of issues raised and a consideration of the implications of our work for issues raised in the CERME 8 *call for papers*.

THINK-ALOUD PROTOCOLS AND TASK-BASED INTERVIEWS

Think-aloud protocols (T-AP) and task-based interviews (T-BI) can be regarded as methodological approaches for capturing data on domain specific problem solving. Both rely on participants' verbal reports and allow opportunities for participants to engage in 'live' reflection on their 'free' problem-solving performance in order to elicit reasoning. Both were developed in the last quarter of the 20th century and were relevant to research foci in expert-novice thinking, which was in vogue in this period. T-BI, but not T-AP, were developed within the mathematics education field. Neither

was initially tied to a specific theoretical framework and both have been used by researchers espousing various constructivist and socio-cultural positions. Ericsson & Simon (1993) and Goldin (1997) are comprehensive expositions of each approach.

A key difference between the two approaches is that T-AP ask participants to 'think-aloud' during task performance whilst T-BI do not encourage this; T-AP afford reflection 'in the moment' by a self-directed participant whilst T-BI afford reflection 'after the act' via interviewer prompts on strategies undertaken. Ericsson & Simon (1993) note that there are different kinds of think-aloud verbalisations, from free association utterances (their Type I and Type II verbalisations, as discussed by Robertson (2001, p.13) involve 'direct verbalisation' and 'recoding of short term memory') to verbal descriptions of everything that the participant is conscious of whilst engaged in the task (Type III verbalisations); a risk with the latter type is that this will frustrate participants' problem solving. The exploration of learner thinking in T-BI has four stages and two goals:

> (a) posing the question ("free" problem solving) …[with] nondirective follow-up questions (e.g., "Can you tell me more about that?); (b) heuristic suggestions if the response is not spontaneous (e.g., "Can you show me by using some of these materials?"); (c) guided use of heuristic suggestions … (e.g., "Do you see a pattern in the cards?"); and (d) exploratory (metacognitive) questions (e.g., "Do you think you could explain how you thought about the problem?"). The clinician's goal is always to elicit (a) a complete, coherent verbal reason for the child's response and (b) a coherent external representation constructed by the child …(Goldin, 1997, p.45).

From a T-AP perspective such 'after the act' verbalisations are 'suspect' as they may provide data on what participants think they thought rather than on their thoughts-in-action; there is also a danger that the interviewer may co-produce knowledge (Hobson & Townsend, 2010). A T-AP approach, however, may not establish coherent verbal reasons for actions and much may remain unspoken, even if the interviewer encourages verbalisations of descriptions of everything in the participant's consciousness. There appears to be no scope for a hybrid form ('networking') of the two approaches[i] to capture data during problem solving since interrupting the think-aloud process with task-based interview style questions or establishing a protocol in which there is a strong emphasis on explaining and describing thinking, may impact upon free problem solving (that both approaches arguably require as a first step). Indeed, Ericsson and Simon (1998, p.180) state that "participants' efforts to describe and explain thinking can change the sequence of thoughts and lead to the intrusion of additional thoughts" thus potentially leading to "interfere[ence] with normal [mathematical] problem solving [processes] by either slowing…[them]…down or affecting the sequence of problem solving steps" (Robertson, 2001, p.13).

STIMULATED RECALL AND *LIVESCRIBE* PENS

Stimulated recall "is one subset of a range of introspective methods that represent a means of eliciting data about thought processes involved in carrying out a task or activity" (Gass and Mackey, 2000, p.1). A stimulated recall interview (SRI) typically involves the use of a stimulus such as an audio or video tape to "enable the participant to 'relive' the episode to the extent of being able to provide, in retrospect, an accurate verbalised account of…original thought processes" (Calderhead, 1981, p.212). Mason (2002, p.63) claims (and we agree) that SRI allows researchers to explore participants' "knowledge, views, understandings, interpretations, experiences and interaction"; there is thus a sense in which SRI and T-AP share ontological and epistemological principles (in the sense that Radford (2008) uses the term 'principles'). Given that a SRI is an 'after the act' replay, there is no reason why a SRI cannot be in two stages: (i) no interviewer prompting; (ii) interviewer prompting. The use of such a two stage SRI could then follow the protocols of both T-AP and T-BI.

Livescribe is the brand name of a digital pen with a built-in digital audio recorder. While it can be used as a regular pen on ordinary paper, when used with special proprietary paper, it records writing to be uploaded to a computer (which can then be played back/animated in real time) alongside the audio of sounds recorded at any point in the script. In addition to this, touching the pen to any point on a 'completed' page of notes/jottings also enables the instant replay of the precise sounds (for example, any conversation occurring at that point in the writing), thereby facilitating recall, should it be required, even without upload to a computer. This last point is very interesting in student playback of problem solving talk/writing as students can hear the talk associated with specific written symbols. *Livescribe* pens thus afford being used as a stimulus in SRI.

AN INVESTIGATION OF COLLABORATIVE PROBLEM SOLVING

Part-time postgraduate primary student teachers at York St John University took part in a pilot project (for the first author's PhD) exploring how digital audio recordings may provide opportunities to engage in closer consideration of, and reflection on, their mathematical problem solving performance. The research question was: how does thinking aloud, supported by digital audio recording, support student teachers' understanding of problem solving. Like most research questions, this one did not appear 'out of the blue', it arose from academic dialogue which tried to 'intellectualise' the first author's prior 'success' in engaging student teachers in 'real' problem solving and his prior experiments in using *podcasts* with his student teachers (*podcasts* were seen as a means to keep part-time students engaged in mathematics during periods of absence from the University). The practical idea 'behind' the research question is: if student teachers can critically reflect on their own problem solving, then this reflection may help them to design learning environments which support 'real' problem solving for their future pupils. The following (supplemented

by a picture of an abacus) is one of the problems the students worked on in self-selected small groups:

Make as many three digit numbers as possible with 25 beads on one abacus.

An assumption behind this work was: student-student discourse during problem solving is important for mathematical development. We value Mercer's (1995) work in this area and consider his category 'exploratory talk' (where participants engage critically but constructively with each other's contributions) as important for mutual development. We also wanted a framework for problem solving and used that of Hošpesová and Novotná (2009), largely due to the connections that can be drawn between their categories and Mercer's (1995) work. A hybrid 'talk and problem solving framework' is detailed in Hickman (2011). This framework includes Mercer's (1995) three categories of talk (disputational, cumulative and explorative) but the explorative category is sub-divided into that in which relevant information is offered for joint consideration in: mathematical form; non-mathematical form.

Independent of this work the second author purchased *Livescribe* pens because he thought they might be useful for research. The first author 'tried these out' and we agreed that they were potentially useful for this research.

The research consisted of student teachers thinking aloud whilst engaging in group problem solving activities with *Livescribe* pens; at this point the interviewer employed a T-AP protocol. Just over a week later the students revisited (with the aid of the *Livescribe* pens) their work to identify potentially beneficially exploratory dialogue; at this point the interviewer employed a T-BI protocol. This 'revisitation' of their work included students using the hybrid framework to categorise particular responses.

It could be said that this 'revisitation' falls short of what some researchers regard as a SRI, for example, "the stimulated recall group…[speak]…their thoughts into a microphone as if talking to [themselves]" (Egi, 2008, p.226). However, the T-BI approach supported by the recorded material picked up by the *Livescribe* pens afforded the students the opportunity to identify themes, to talk to themselves and to reflect on the performance of their earlier 'selves'.

This pilot study was not without problems. Sometimes connections with mathematics recently engaged in were not noticed and this appeared to be linked to the presence of the digital audio recorder and the associated talk protocol, which, some students in the SRI claimed, impacted on their performance:

> Well, we knew that we *had* to discuss it in this way...

Some began speaking *before* they had fully considered the problem:

> I would have preferred to have had time on my own to look at it first and then come into it because...solutions started being talked through before I was at that point.

This indicates that, however important talk protocols may be, additional 'ground rules' are required before beginning a task of this kind. The same issues may have impacted upon the use of the *Livescribe* pens (i.e. making jottings because they felt they 'had' to) but the presence of the notes and the *Livescribe* pen often provided evidence of exploratory contributions that would not otherwise have been evident, 'making up for' and, ultimately, enhancing the quality of the original mathematical discussion. Participants were able to identify their exploratory comments more effectively within the *Livescribe* supported SRI than had been the case via their original T-AP (one potential cause of their less successful listening to each other's contributions being their level of concentration on their own verbal contributions and awareness of being recorded). For example, in the SRI (but not in the T-AP) of the *abacus problem*, participants noted that they had, in fact, been presented with a problem similar to one that had previously been encountered (indeed, the problem had been chosen for this reason). Therefore, the *Livescribe* supported SRI afforded students the opportunity to make connections, from their original contributions and working, that had not been explicitly identified in the original problem solving session. In the original recording, one participant cautiously observed:

> This is like one of the problems we did last week where after a certain number, you have to … you have … yeah…

Given the 'unfinished' nature of the verbalised thought, it is unsurprising that it was not effectively built upon (in Mercer's (1995) 'cumulative' fashion); it took the *Livescribe* SRI to make it clear to participants what had originally been propounded.

CERME PARTICIPANTS' VIEWS ON METHODOLOGY

In this section we outline our interpretation of the views of 'methodology' in Radford (2008) and in Artigue, Bosch & Gascón (2011). We select these papers because they deal with 'networking theories' and we critically value them.

Radford (2008, p.320) suggests that "a theory can be seen as a way of producing understandings and ways of action based on: … *basic principles* … a *methodology* … paradigmatic *research questions*". The principles (P) are a 'system' of unequally weighted 'elements' (views or statements) on pertinent constructs such as cognition, learning and social interaction; Radford would say that our statement above, "student-student discourse during problem solving is important for mathematical development", is a principle. Radford adds that "there is a *hierarchy* that organizes and prioritizes them" (ibid.). Our statement was explicit, behind our statement is an implicit view that development is cultural and is mediated by language.

Radford (ibid.) states that a 'methodology' (M), "includes techniques of data collection" and may go beyond 'positivistic' data collection. The word "includes" suggests that there is more that can be said about a methodology – we agree! Further to this a methodology must have *operability* (produce data to address research questions and distinguish between relevant and irrelevant data) and *coherence*

(consistency with principles); relevant data is that in which there is coherence between the principles and the methodology of a theory.

Paradigmatic *research questions*, Q, are "templates or schemas that generate specific questions as new interpretations arise or as principles are deepened, expanded or modified" (ibid.). "Expanded or modified" suggests a 'state of flux' in the 'lives' of theories with Radford further stressing 'flexibility' and interrelations between P, M and Q. Both of these aspects endear us to Radford's approach but, despite the interrelationships, P, M and Q are distinct in Radford's exposition. We return to this in the next section and now turn to Artigue et al. (2011).

Artigue et al. (2011) is a novel but straightforward application of Chevallard's (via Mauss's) construct 'praxeology' to the phenomena of theorising. We refer the reader to Chevallard's CERME address (Chevallard, 2006) for an exposition of this construct but outline the terminology below.

A praxeology consists of four elements [T/τ/θ/Θ] in two pairs, "[T/τ] corresponds to the 'practice' … *types of problems* T that are approached and the *techniques* τ … [θ/Θ] forms the *technological-theoretical* discourse used to describe, justify and interpret [the practice]" (Artigue et al., 2011, p.2). This language underpins an epistemological model. An immediate insight from this perspective is that "talking about 'theories (as in the expression of 'networking theories') is the result of a metonymy used to point to the whole – *research praxeologies* – by only indicating one part, the theoretical block of praxeologies." (Artigue et al., 2011, p.2) It appears possible to replace the word 'technique' with 'methodology' in the case of research praxeologies and this certainly can be done in some research praxeologies but we feel that part of a methodology can be located in the technological component in our research.

An important adjunct in Artigue et al.'s (2011) consideration of research praxeologies is the construct (didactic) 'phenomenon', "empirical facts, regularities that arise through the study of research problems" (Artigue et al., 2011, p.3). Our informal interpretation of such phenomena is *what is important/striking in the research under consideration?* As an aside, we believe that this construct could be used to partition papers in recent CERME 'theories working group' into those with a (and those with no) central phenomenon; in the latter case there would appear to be a sense of 'networking for the sake of networking'.

Artigue et al. (2011) state "our approach is fully coherent with that developed by Radford (2008)". We too see commonalities in these two approaches but their distinct ontologies means that there can be no isomorphic mapping between them.

DISCUSSION

Our focus in this section remains on methodological issues. We address two issues: the role of *Livescribe* pens in 'networking methodologies'; whether T-AP and T-BI are simply methodological approaches for capturing data. In considering the second

issue we explore the views of methodology in Radford (2008) and Artigue et al. (2011) with regard to our research.

We present an argument above that there is no scope for 'networking' the two approaches to capture data during problem solving. However, the *Livescribe* pen allows for an initial T-AP interview to be 'played back' in an SRI with a T-BI protocol. There is a real sense in which this artefact affords networking these interview approaches. With regard to Radford's (ibid.) view that a 'methodology' (M), "includes techniques of data collection and data-interpretation as supported by *P*" our use of both T-AP and T-BI could be seen as 'opportunistic' research which compromises basic principles (using the principles of T-AP in the initial interview and the principles of T-BI in the SRI). We, however, consider that the *Livescribe* pen allows the researcher to 'link' the initial T-AP activity and the subsequent T-BI activity whilst retaining the principles of both (but separately in the two stages of the activity). In terms of Goldin's (1997) four stage exploratory process T-AP are used (appropriately) in the free problem solving first stage and the remaining three stages (heuristic suggestions; guided use of heuristic suggestions and metacognitive questions) follow within the SRI. There is thus a sense in which the *Livescribe* pen does more than network interview approaches; it contributes to a 'stronger' T-BI protocol as heuristic suggestions, for example, may be more readily identifiable via a combination of 'jottings' and comments (most especially those that are, as discussed above, not fully verbalised) than through a written record or audio recording alone. Furthermore, it is arguable that, knowing that the *Livescribe* recording will preserve and actively connect these ordinarily disparate elements ensures that there is less necessity for an onerous verbalisation protocol, thus supporting the initial free problem solving.

We now consider whether T-AP and T-BI are simply methodological approaches for capturing data. We continue with a consideration of the Radford (2008) quote above but now focus on the word 'includes'. Radford is 'hedging' here. A methodology certainly includes data collection and analysis techniques, but many researchers, we feel would replace 'includes' by 'are'. We support Radford's 'includes' but (like Radford, we suspect) find it difficult to state (in the abstract) what a methodology holds beyond data collection and analysis techniques. We prefer to approach the abstract in this matter via the concrete: are T-AP and T-BI simply data collection and analysis techniques? Our view is 'no', they have evolved into quasi-theoretical approaches where an implicit (and flexible) 'theory' is intertwined with an explicit methodology. We have not explicitly researched their evolutions but both approaches were developed over a period long before the publication of Ericsson & Simon (1993) and Goldin (1997). We further suspect that each has two types of 'principles', explicit principles associated with data collection and analysis techniques and flexible implicit principles which may be appropriated by researchers of a variety of 'theoretical' approaches (e.g. constructivists and activity theorists

amongst others). We hold that there is an historical 'irreducible bond' between theory and methodology in the various research uses of both T-AP and T-BI.

We now turn our attention to Artigue et al.'s (2011) research praxeologies but continue to consider the 'includes' vs 'are' matter above. In the language of Artigue et al. (2011), being in the 'are' camp would place methodology in the [T/τ] 'practice' pair of a praxeology. In the words ABG use, there are indications that they are in the 'are' camp; "Some of these phenomena enrich the initial theoretical framework to produce new interpretations and techniques or research methodologies" (p.3). But Artigue et al. (2011) was the first paper on this matter. In a more recent paper (Bosch, 2012, p.3) there is a suggestion that a part of the methodology can reside in the *technology* (θ) part of the *technological-theoretical* [θ/Θ] pair.

> Dans le cadre des PR, le niveau technologique permet de distinguer, dans le bloc théorique de description, interprétation et justification de la pratique, un ensemble d'éléments plus variables et mobiles que constituent le premier niveau de description des techniques, la « technologie », de la « théorie » formée par des principes et hypothèses plus stables qui font partie du « noyau dur » de la praxéologie et qu'il est plus difficile de faire évoluer sans que la construction complète en soit altérée. De cette manière, la prise en compte du niveau technologique des praxéologies de recherche permet de clarifier la relation, généralement assez obscure, entre une théorie scientifique et sa méthodologie de recherche.
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> In the framework of research praxeologies, the technological level permits one to identify, in the 'theoretical block' of (or which contains) the interpretation and justification of the practice, a body of more variable and mobile elements which make up the first level of descriptions of techniques – the 'technology'. The 'theory' IS formed by the more stable principles and the hypotheses which are part of the 'hard core' of the praxeology and which are difficult to evolve without the complete construction being altered. Taking into account the technological level of research praxeologies allows a clarification of the relation, which is generally obscure, between a scientific theory and its research methodology.

This certainly 'makes sense' to our way of thinking, as a technique requires a rationale, a *technology* in the language of Artigue et al. (2011). We look forward to discussing this matter with the authors at CERME 8.

Summing up the considerations above, on what a methodology is, we focus on the concrete practice of researchers. 'Methodology' is a word to describe a part of this practice. The word should not be reified to hold mysterious qualities beyond concrete practices. In the concrete practice of some, but not all, researchers, a methodology 'is' a technique (resonances to Marx's 8th thesis on Feuerbach in this paragraph are intentional).

IMPLICATIONS

Our considerations in this paper impinge on the following themes in the 'call for papers':

- Examples of strategies for connecting theories [methodologies]
- Conditions for a productive dialogue between theorists [methodologies]
- Difficulties and strategies when gathering results from different frameworks
- The role of the empirical material (research data) in the networking and design of theories
- The interaction between contexts and theoretical approaches: the diversity of approaches towards context in different didactic cultures

Specifically this paper raises three issues for the on-going discussion of the CERME 'theory group'. First, it raises the issue of what a methodology is and its relationship with 'theory'; this is useful as methodology has been somewhat of a 'poor relation' in the past considerations of the CERME 'theory group'. Second, it suggests that an artefact, the *Livescribe* pen (together with SRI), can enable the networking of theories/methodologies (and possibly build a stronger theory-methodology in the process). Third, it encourages a reconsideration of the work of past CERME 'theory group' participants, Radford (2008) and Artigue et al. (2011), views on theories and methodologies; we say above "there can be no isomorphic mapping between them" but perhaps we can consider how these two meta-theoretical stances can be networked.

NOTES

[i] Individual researchers are, of course, free to do whatever they want in their research but, from the point of view of this paper, taking a bit of T-AP and bit of T-BI in a single research protocol would result in an approach that was neither T-AP or T-BI in principle.

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