Mathematical Understanding in a Vocational Context: An Exploration in Applying a Stimulated Recall Technique Using Video

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Abstract

Extracting data containing information about cognitive processing in workplace settings can be a difficult exercise, particularly as cognitive functioning cannot be accessed directly but only through observation of action. When the task being observed is of a highly practical and individual nature, concurrent verbalisation of action is not normal practice. This makes accessing the thoughts of the participant particularly difficult and requires thoughtful and targeted methods to provide authentic data to inform cognitive processing. This article presents the derivation a four-step stimulated recall technique which has proved valuable in gathering such authentic data useful in identifying mathematical cognition in plumbing trade apprentices.

Introduction

Competence in a chosen vocation is of importance to the majority of the population. Such competence also extrapolates beyond that of the individual encompassing collectives, therefore impacting on respective workforces. Cornford and Beven (1999) stated that a skilled workforce is the key to national wealth and economic ascendancy; an idea that has been adopted by various governments in Australia, leading to calls for a ‘knowledge nation’ (Chifley Research Centre 2001).

Mayer (1992) listed a number of fundamental competencies required for effective participation in work, one of which being the use of mathematical ideas and techniques. In terms of education and training, the ‘practical or functional application and use of mathematics’ has been identified as a key area (National Centre for Vocational Education Research 2001 p.2). Such a focus for research has not been limited to Australia, and previous studies have covered a wide range of contexts. Some of which include: the mathematical knowledge of carpenters (Milroy 1992); street-vendors (Carraher et al. 1985); shoppers (Lave et al. 1984); understanding of floor plans (Clarke & Helme 1993); carpet layers (Masingila 1992); paediatric nurses (Noss et al. 2000); bankers (Noss & Hoyles 1996); technological workers (Sträßer 1999), technical drawing of engineers (Sträßer & Bromme 1992); book makers (Schliemann & Acioly 1989); building industry workers (Eberhard 2000; Fioriti & Gorgorio 2001); retailers (van der Zwart 2000); reading of building site plans (Bessot 2000); and jewellery makers (Hahn 2000).

Predominantly, research has been concerned with the identification of what mathematics is used. Whilst these inspections are worthy and important to the field, research which has moved ahead from this search for 'how much' to looking at the quality of responses are recent and rare. Studies such as those by de Aguero (2003) into the differences in painters' schemas for solving the same workplace problem, have begun to delve deeper into the notion of the 'quality' of workers' mathematical behaviour. Such behaviour in workplace contexts is intrinsically related to actions such as planning, making judgements, and problem solving, as opposed to just listing the mathematics in use. All of these actions require a certain level of mental functioning, or cognitive performance. Consequently, it seems reasonable to propose that cognitive theory could provide a mechanism by which levels of quality could be identified and analysed (Inglis & Pegg 2003).

Methodological problems in uncovering mathematical behaviour

In attempting to uncover the quality of workers' mathematical ideas and techniques on a cognitive level, researchers face at least two major difficulties. The first of these is that workers do not often recognise the mathematics they are using. The second is that such cognitive functioning is not directly measurable (Biggs & Collis 1982). These two difficulties were the major influence on choosing to use a Stimulated Recall Technique to collect the data, and are therefore explored in the following discussion.

Workers do not recognise the mathematics they are using. There are two possible explanations for the first difficulty that workers often do not recognise the mathematics they are using, both of which are related to the fact that workplace mathematics is embedded in context (e.g. Noss et al.2000; Sträßer 1996, 1999). In the first instance, it may be that workers often do not recognise the mathematics they are using because it is hidden within artefacts/technology (Sträßer 1996, 2003). The second is that the most easily recognisable mathematics is that oriented to schooling, and yet "practitioners' epistemologies of quantity, space and time can differ fundamentally from those anticipated from a school mathematics orientation" (Noss et al. 2000 p.33). Noss et al. (2000 p.32) label these epistemologies as *situated abstractions*, defined as the 'practitioner's conceptions of the mathematics they use at work.' These situated abstractions of workers are generally limited to the four major mathematical operations of addition, subtraction, multiplication and division (Foyster 1990; Milroy 1992), or standard arithmetic algorithms (Wedege 2002).

Mathematics in use may be neither important nor accessible to the worker. From the workers' point of view, the importance of knowing that mathematics exists is likely to be minimal where mathematics is interwoven within workplace problems. They are more likely to see occupational and professional concerns as being more important (Noss et al. 2000), and hence afford more attention to those than to overt mathematics. Instead, the worker uses strategies to minimise time taken and maximise monetary gain. The workers' access to mathematics is also less likely in circumstances where efficiency implies automaticity. Cognition that is automated is generally not accessible to the individual (Ericsson & Simon 1980), and hence it is not surprising that workers do not recognise the mathematics that they are using.

For these two reasons, minimal importance and inaccessibility, research which asks the worker 'What mathematics do you use?' may give undesirable response effects leading to invalid and/or unreliable data on actual workplace practice.

Access to cognitions. The second major methodological challenge faced by researchers attempting to explore the quality of worker's mathematical cognition is that cognitive behaviour cannot be measured directly by the researcher, and must instead be gathered by observing the actions and gaining access to the thoughts of the participant. Consequently, in order to assess the quality of workers' mathematical cognitions, the researcher needs not only to gather information using techniques such as field notes and observations, but also to access the worker's cognitive perspective. The most common method to gain such access is by interviewing the participant. White and Gunstone (1992 p.65) stated:

> *An interview about an instance is a deep probe of the student's understanding of a single concept, that checks whether the student can not only recognise whether the concept is present in specific instances but also whether the student can explain his or her decision. The explanation reveals the quality of the student's understanding.*

Interview methods are commonly used to obtain participants' experiences and points of view. In studies of workplace mathematics, there appear to be three main types of interview method: (i) participant verbalisations of practice in 'real-time', (ii) participant reflections on action after the event, and (iii) participant reflection on action after the event stimulated by reflective prompts.

In the first type of interview, the researcher is often immersed in the workplace, with explanations given by the worker during the task performance. This procedure has not been without some criticism, particularly because of the potential for concurrent verbalisation to cause 'an unacceptable degree of interference with task performance' (Marland 1984 p.157). Thinking-aloud strategies have also been documented as placing additional strain on working memory and impeding 'best-practice.' Studies such as those by Dickson et al. (2000) proposed that using concurrent verbalisation to study cognitive processes in task execution could have 'reactive effects on task processes and downgrade performance.' However, despite the limitations, such strategies have the benefit of providing the participant with the opportunity to explicate practice in the presence of salient cues in real-time.

The second type of interview involves obtaining reflections on a lived event. These data are collected after the event to potentially provide insight into the participants' point of view. Generally, such interviews are semi-structured and seek to clarify issues which arose during the observation (see, for example, Hogan & Morony 2000 p.104). What such interviews cannot guarantee is accurate recall, due the absence of appropriate stimuli.

The third type of interview involves the participant providing thoughts on or in action after the event, but stimulated by appropriate cues. Initially, the task is performed and then followed by interview session; static artefacts (such as photos) and targeted verbal probes are on hand to provide the cues and stimulate recall. In support of such methods, Sträßer (2000) stated that stimulated response type research was superior to traditional interview and survey studies. The reasons for this being that the richness of the data collected allowed the researcher the potential to uncover the hidden mathematics of performance.

An example of such a study examined the mathematics in use by investment bank employees, paediatric nurses and commercial pilots (Noss et al. 2000). In relation to the data-collection methodology they stated the following:

> *A series of task simulation interviews was devised, based on a selection of workplace activities and contexts. The majority of the simulations recreated the breakdown episodes witnessed during the ethnographic observation. Each scenario was made as 'real' as possible, by the use of context-rich descriptions of the activity, with supplementary information provided in the form of familiar resources and visual displays: e.g. copies of blood pressure charts, screen shots of instrumentation (p.21).*

These interviews provided insight into the participants' reasoning whilst allowing the researchers to manufacture novel situations. However, this type of method does not provide information regarding actual workplace practice, as such 'simulations' cannot be said to provide salient cues in real time to the participant. Contrived episodes of simulated workplace practice are to some extent decontextualised: devoid of the affective factors influencing performance in an actual real-time task.

For interviews that rely on participant reflection on a certain task, the quality and authenticity of the data gathered is directly related to the appropriateness of the cues provided to stimulate recall. The accuracy of either explanations of practice, or thought-in-action, rely heavily on the provision of salient cues to stimulate such recall. One way of providing salient cues to stimulate recall is by using videotaped recording of task performance. As much as possible, these perspectives of the video should reflect the participants' line of sight to maximise possibility of accurate recall in the stimulated recall interview sessions.

Traditionally, video recordings have been used by researchers in triangulation with other data sources such as field notes and artefacts, providing additional real-time data in context. Video data have the ability to:

- preserve subtle aspects of performance (eye gestures, body posture, intonation, environmental noises and subsequent interactions)
- allow for repeated examination of data,
- have no intrinsic bias
- are flexible with regard to setting types.

Although such data increases the validity of analysis when used within mixed-methodological studies, issues of researcher subjectivity must still be addressed. Using video-data of the lived event as a stimulus for an interview however, can provide data from the participant's point of view, enabling some minimisation of researcher subjectivity in analysis.

Literature Review

One possible data gathering methodology proposed to generate data from vocational contexts is stimulated recall. Stimulated recall (also referred to in behavioural sciences as interpersonal process recall (Kagan & Kagan 1991)) is a technique designed to provide access to the cognitive processes of human problem solvers during performance tasks (Marland 1984). First pioneered by Bloom in 1956 to study the thought processes involved in university students' discussions, the most typical instances of stimulated recall as a defined genre of method have been to examine the 'in-flight' (Paterson 2000 p.44) thoughts of teachers (e.g. Marland 1984; Paterson 2000; Stough & Palmer 2003) and the reflective practice in the teaching and learning of physical activities (e.g. Lee 2002; Parker & Pittney 2003; Solomon & Lee 1997). Although these areas of research are not exclusive, these two authors have found no overt uses of this technique in existing literature on mathematics in vocational contexts.

Stimulated recall predominantly involves the use of mechanically recorded data (audio or video) consisting of a participant's behaviour (visual and audio) whilst they are carrying out a particular task, to 'stimulate recall of simultaneously occurring thought processes' (Marland 1984 p.156). The common underlying rationale for research using a stimulated recall method is that it potentially provides the participant with appropriate stimuli to be able to relive an original situation.

Marland (1984 p.157) described the use of stimulated recall in circumstances where think-aloud methods would cause 'an unacceptable degree of interference with task performance.' More recently, Dickson et al. (2000 p.220) cautioned against the use of concurrent verbalisation regarding in-task execution as it may have 'reactive effects on task processes and downgrade performance.' To maintain the internal validity of the data, these issues must be taken into account, particularly when the day-to-day execution of tasks being observed are executed without such concurrent verbalisations.

Stimulated recall is a powerful methodology for data collection (Paterson 2000); however, special care must be taken in its application. To date, no singular optimum way for applying the technique has been determined, with individual research circumstances dictating the particular methodology required. Keith (1988 p.8) raised three questions which a researcher should pay attention to regarding adoption of a stimulated recall technique:

- possible bias in the questioning
- the nature of the stimulus
- the availability of interactive thoughts for recall.

Bias in the questioning. Bias in the questioning appears to manifest mainly within the nature of the probes being directed at the participants during the interview. These probes may cue the participants to certain areas that the researcher may wish to focus on, and must be carefully monitored to reduce response effects. Keith (1988) suggested that one way of reducing these response effects was to use unstructured interviewing techniques. Questions such as ‘stop the video when you want to discuss what you see’ or ‘tell me what is going through your mind’ can be used to direct the participants to what is required from the interview. In order to reduce distortion of the participants’ verbal data, the probes must remain neutral. This makes it less likely that the participant is prompted and their self-reporting data distorted from what they otherwise would have said (Yinger 1986).

The nature of the stimulus. Marland (1984) made two assumptions regarding aural or visual stimuli. Firstly that such stimuli should provide sufficient cues to “stimulate accurate and near-complete recall of mental processes” (p.158) and secondly that the presence of the recording hardware should not change the nature of the performance in a research setting. To address the first point, stimulated recall proponents generally assume that the up-close and uninterrupted record of performance prompts participants to recall as accurately and realistically as could be expected, providing in-flight thinking at the time of the event. Additionally, provision of optimum recall conditions require that the recorded data must be as close as possible to the perceived view of the participant.

Despite these assumptions regarding the methodology, the extent to which retrospective reports on in-flight thinking can be considered accurate sources of data fluctuates depending on the researcher. Critics such as Yinger (1986 p.273) argue that at best, stimulated recall is only “tangentially related to actual thinking during the recorded event and at worst be entirely fabricated,” and added that it is more likely to be ‘reflection-on-action’ rather than ‘reflection-in-action.’ Such terms relate to whether the participant is describing what they see themselves doing, as opposed to reflecting on what they remember thinking at the time. However, close examination of the transcripts of the interviews can provide useful clues to filter such data. For reflection on action, these clues would include verbalisations in present tense, whereas reflection on action would tend to be exhibited through past tense.

The second point to be raised is associated with the stimuli, and refers to the effect of the videotaping itself on the initial task performance. Marland (1984) stated the importance of keeping the setting naturalistic; this can be done by:

- establishing a rapport with the participants prior to the data-collection sessions whereby making the participants feel at ease with the researcher
- establishing a comfortable precedence with the presence of the video camera by recording the everyday goings on in the context
- making sure that the participants understand the focus of the research clearly
- that the videotaping does not unduly disrupt the naturalistic setting.

An additional complication with regards to the nature of a video stimulus deals with the effect of viewing oneself. Keith (1988) and Yinger (1986) both stated that such an experience was likely to have an impact on the authenticity of reports of perceived in-flight thinking.

Availability of interactive thoughts for recall. As mentioned earlier in this paper, when performance becomes automated, these behaviours are often unavailable for verbalisation on a cognitive level. This is supported by Keith (1988 p.12) who stated that in studies of classroom teachers, tasks of an automated nature were ‘not available for verbal reports because [participants] are not aware of them’, therefore ‘it may well be impossible for teachers to describe their highly automated interactive decisions and the cues used to make them, even if they wanted to do so.’ Therefore, stimulated recall interviews need to be carried out no more than 48 hours following the event. The theory underlying this restriction is related to short and long-term memory which is beyond the call of this paper; however, the reader can consult Ericsson and Simon (1993) and Ericsson and Kintsch (1995) for examples of this work.

The availability of interactive thoughts for recall is closely related to the idea that cognitive processes cannot be measured directly (Biggs & Collis 1982; Paterson 2000), but observed by associated processes. As such, interviews carried out by stimulated recall using videotape potentially suggest that participants are ‘responding not only to their memory of the viewed situation, but also to a set of cues supplied’ (Yinger 1986 p.269). Therefore, data can only be interpreted as a combination of recall and construction of thought, as the participant is not likely to be able to discern between the two (Yinger 1986 p.270). Such criticisms can be overcome by accumulating knowledge of the event prior to the main data collection in ‘order to present the “right” stimuli for the worker’ (Sträßer 2000 p.245). Additionally, criticisms of stimulated recall techniques that propose that the participant responds primarily to the stimulus and secondarily to the thoughts that occurred at the time of the event (Yinger 1986) can be partially addressed by careful analysis of the discourses collected.

Calderhead (1981) stated that it was unlikely that stimulated recall would be used as the sole data-collection instrument in a research design. Recent research methodologies using stimulated recall have involved mixed-methodological constructs (Corrigan 2001; Ethell & McMeniman 2000). Triangulation of data collection techniques (such as researcher field notes and observations, stimulated recall techniques and semi-structured interviews) have strengthened the validity of the data collected as being authentic representations of thought-in- (or -on) action.

Evolution of a four-step stimulated recall procedure

The preceding review of the literature on the use of stimulated recall using video, identified three points requiring careful attention when used to collect rich and authentic data. These are bias in the questioning, the nature of the stimulus, and the availability of interactive thoughts for recall. A fourth point not identified in the earlier review relates to the analysis of the data obtained. In the present study, where the focus is on mathematical cognition, the theoretical framework for analysis is the Structure of the observed Learning Outcome (SOLO) Model.

To reduce incidents of *bias in questioning*, the use of probes such as ‘can you tell me what you were thinking here’ and ‘what thoughts were going through your mind’, were employed. As intended, the participants were then able to give responses which were from their point of view as opposed to what they thought the researcher wanted. This technique also ensured that the mathematical focus of the study remained hidden from the participants, allowing collection of data which could also determine whether the participants were overtly or covertly using mathematics in their solution strategy. As such, their responses in the stimulated recall interview sessions were varied and often did not contain references to mathematical concepts. An example of this relating to issues important to them, such as how much ‘easier it would have been to have the use of hydraulic tools’.

Another point in achieving a rich and authentic source of data was directly related to the *nature of the stimulus*. As mentioned previously, there are many factors that influence the ability of the stimulus to provide sufficient cues to stimulate accurate recall of in-flight thinking by the participants. Of particular interest in this pilot study, was the solution to three main questions:

- was the setup and choice of task appropriate?
- was the video a suitable stimulus for the participant to enable verbalisation?
- was the level of rapport between the interviewer and participant sufficient to enable verbalisation?

The participants appeared to have little trouble deciphering the Job Sheet provided and the direction on the task. The direction given was that they had to complete the task as closely as they would if they were at work. The first two participants both commented that if they were on the job site, they would just copy an existing downpipe, or that they had an angle that they used for all downpipes; rarely would they use a prescribed angle for fabrication. Therefore, for the third participant, additional context was added:

> *Your boss has got a job in progress out of town. Job specifications have stated that the angle of the downpipes have to be set at 120°. Due to time and vehicle constraints, he has asked you to stay at the workshop today and make up the other three from the Job Sheet provided. This is so that you can save time tomorrow and just fit them straight to the gutter.*

This additional element of context made sense to the third participant, and who then could place this task in a real-life setting. This motivational and contextualising element of task completion was an important, yet previously unidentified, component in obtaining valid data and as such, was added in the Main Study.

The preparation of a video record which would provide an appropriate stimuli was another important element in the use of stimulated recall. The presence of the video camera in the TAFE workshop on the morning of the visit was a novelty initially, with the apprentices interested in seeing themselves on tape. This recording of the class as a whole proved highly important; it dispelled much of the anxiety felt by the individual performance being recorded. With only one day in which to carry out this data-collection for each of the three participants, the lack of comfort with the presence of the video camera was apparent when the participant was videoed in the afternoon individually performing the given task. Despite the task execution being carried out apart from the class cohort, two of the three participants were anxious at beginning the task. Such anxiety soon dissipated once the participants began to concentrate on task execution.
Following experimentation of various taping positions, the participant's direct line of sight was ruled out due to the dynamic nature of the task. A camera angle directly in front of the participant from the chest down was considered the most appropriate. The camera was mounted on a tripod in such a way as to show all the required workspace. The participants were asked to look through the camera so that they knew the limitations of the field of view.

It was important show respect for the participants in their environment. To minimise the possibility of causing embarrassment or anxiety to the participants, the researcher maintained a low profile within and around both the participants and the cohort of the class during the data-gathering phase. Anxiety was further reduced by leaving the participant to complete the task independently, and apart from the class cohort and researcher presence.

The interviewer/participant rapport was highly important in the interviews. Firstly, this relationship, nurtured prior to the task execution, was important to overcome feelings of anxiety mentioned earlier. Highly influential to this end were assurances of confidentiality of performance. Secondly, verbalisation of thoughts and a free flow of such information from the participant was a difficult balance of probes and general conversation, as well as interest from the researcher in the vocation of the participants and the immediate task performed.

The third point necessary in assuring rich and authentic data was the *availability of interactive thoughts for recall*. The open-ended interviews using the video as the stimulus was a successful approach in providing a level of verbalisation of thinking or explanations about the task for these participants. All those interviewed described something about their thinking processes, but most of the content of the responses was closely related to explanations of *why* certain actions were taken. In many cases, participants gave a running commentary of what they saw on the video. These actions cannot be discounted entirely as they are connected in some way to the participants' thoughts due to the automated nature of the task (see Fitts 1964). Indeed, despite the 'pure' vision of a stimulated recall technique assuming that subjects recall only what they were thinking at the time of the event by viewing a stimulus, more liberal stimulated recall researchers 'adopt the position that what people think influences directly what they do' (Marland 1984 p.158). As such, these apprentices' explanations or reflection-*on*-action (as opposed to reflection-*in*-action) could have been a direct influence on their performance at the time. In terms of a stimulated recall methodology for this study, such verbalisations are important for understanding cognitive functioning and decision-making. Such data, whilst not the primary aim of a stimulated recall technique, 'will better provide understanding of the information processing skills and styles that characterise … performance' (Marland 1984 p.158). Such verbalisations were not discounted and enriched the data for analysis using the proposed cognitive framework. Gathering data useful in gaining insight into the participants' mathematical understanding relating to the task proved to be the most difficult factor in this study. As alluded to earlier, the participants were not aware that the focus of the research was on mathematical knowledge and skills. Responses to the stimulated recall interviews by all participants gave important information regarding and explanations of actual practice, providing some information of the participants' mathematical understandings related to this task. However, there were particular sections during the fabrication of the downpipe which the researcher deemed useful to enable mathematical coding; one example being the need for the second bend to be the same as the first so that the two vertical arms of the downpipe would be parallel.

The fourth point is the analysis of the data collected using a cognitive framework. The cognitive framework utilised in the present study was the SOLO Model (Biggs & Collis 1982). This model provides a structure that can be used to measure human knowledge, by identifying 'how well' (qualitative) something has been learned, as opposed to the more traditional approach of measuring 'how much' (quantitative). SOLO can provide a system by which a response can be classified not only in terms of how much content knowledge a person has regarding a particular concept, but also the depth of knowledge possessed. The scope of this paper does not lend itself to a discussion of the model in depth, however the reader is directed to work by Biggs and Collis (1991), Pegg (e.g. 1992), and Inglis and Pegg (2003) for further information.

Discourse analysis using the SOLO Model as the theoretical framework, provides a mechanism by which a link can be made between the data collected and mathematical cognition. With lengthy practical tasks underpinning the data collection, it was necessary to identify Key Performance Stages of the task. These stages were points in the performance where the participants made choices about the next step, but were not in themselves in the present case, inherently mathematical. These *Key Performance Stages* were:

1. The set-up of the task prior to initiating fabrication, i.e., the scale drawings required to establish actual measurements for the downpipe
2. Making the first bend
3. Establishing the offset, or measurement and angle between the first and second bends
4. Making the second bend
5. Underlying knowledge of the job as a whole, i.e., possible cause and effect scenarios.

These indicators identified important markers of mathematical elements of the task. Such markers allowed the researcher to identify whether the participant had mentioned these in the interview. If not, the researcher could ask about the points that were missed in a semi-structured interview on completion of the stimulated recall interview. This enabled data to be collected containing the participant's point of view without response effects, whilst the semi-structured interview added insight regarding mathematical cognitions.

Discussion

The Pilot Study resulted in the design of a specific data-gathering procedure to enhance the quality of data collected. The following procedure potentially provided avenues by which to gather data from the participants' points of view, whilst also to providing data rich enough to inform a predetermined conceptual analysis. Specifically, this four-step stimulated recall procedure consists of:

- Derivation of 'Key Performance Stages'. Such indicators of the mathematical components of the task performance need to be pre-determined by some means.
- Mechanical recording (in this case video) of the task in accordance with stimulated recall guidelines (Marland 1984).

- Collection of verbal data comprising in-flight thinking or explanations of action by using a stimulated recall interview. At this stage the researcher needs to note whether the participant has addressed all points in the Key Performance Stages.
- A semi-structured interview based on what the participant has not addressed in the Key Performance Stages.

Although questions regarding internal validity of this method provide the main barriers to its use, the authors concur with Marland (1984 p.164) who stated:

> *In spite of … problems and limitations, there is a generally held view among those who have used stimulated recall that the technique does offer fruitful means of exploring cognitive concomitants of human behaviour in the classroom and other task settings, and of developing new insights into important enterprises …*

Initial findings based on the use of this proposed stimulated recall protocol in the setting described were promising. The four-step stimulated recall procedure produced rich qualitative sources of data appropriate for analysis using a cognitive framework, whilst maintaining the authenticity of the participant's point of view. Overall, the stimulated recall method provides a tool to gain insight into workers' mathematical cognitions, but must be set up carefully in order to assure the provision of appropriate cues to stimulate recall.

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