Exploring the use of a cartoon as a learner scaffold in the planning of scientific investigations

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Despite curriculum imperatives, in South Africa and worldwide, for learners to have more autonomy in investigations, they remain largely teacher controlled with learners having only limited opportunities in planning. This design-based study explored how a cartoon can be employed in a Grade 9 Natural Sciences class in prompting learners to plan investigations. This innovation followed a continuous cycle of design, enactment, analysis and redesign, synonymous with design-based research. Data were collected through classroom observations of the cartoon being used in practice by a Grade 9 teacher, and interviews with her. The effectiveness of this innovation was established by assessing learner plans using an adapted rubric. The findings indicate that a cartoon having an extended dialogue between characters on a science concept, accompanied by a prompt sheet, is an effective support mechanism in planning investigations. Using this support mechanism, learners were able to write a plan which included stating the problem, formulating the hypothesis, identifying variables, apparatus and a step-by-step procedure for conducting the investigation as well as describing how the collected data would be analysed to address the stated hypothesis. The findings also reveal that such a support mechanism, apart from shifting learners towards more autonomy, does invite learners to engage in the scientific discourse, which often serves as a barrier to science learning.

Keywords: scientific investigations; cartoons; practical work; autonomy; planning; prompt sheet

Introduction

Practical work in the school science curriculum has formed the focus of curriculum reform initiatives which have taken place in various countries such as the United States, the United Kingdom and, in particular, in South Africa. An inquiry-based approach to practical work is promulgated in the South African science curriculum (Department of Education, 2002) which advocates learner autonomy in scientific investigations. This emphasis on the inquiry approach stands in stark contrast to the traditional laboratory approach associated with older curricula where learners often slavishly followed teacher directions and procedures without much thought (Hodson, 1993).

Over the past decade there has been increasing research interest on learner-centred, inquiry-focused learning environments. International studies have revealed that, despite curriculum imperatives for learners to have more autonomy in doing investigations, practical work remains largely teacher controlled (Bradley, 2005; Trumbull, Scarano & Bonney, 2006) and unrelated to the everyday experiences of learners (Stears & Malcolm, 2005). The situation is even more desperate in South Africa's township schools. Here, factors such as a lack of laboratory resources, large classes and a lack of teacher competence result in learners having only a limited experience of doing practical work (Onwu & Stoffels, 2005). The need for these learners to have a quality learning experience in science is highlighted by Alant (2010:2) who states that the lack of success of black learners in mathematics and science is the "most significant obstacle to African advancement in South Africa". Furthermore, studies show that at schools where practical work does take place, it tends to be dominated by teacher demonstrations and a cookbook approach where learners merely follow the teachers' directions and, in general, learners have only limited autonomy in planning investigations (Rogan & Aldous, 2005). The learning benefits of this cookbook approach are questionable. There is therefore a need to shift learners towards greater autonomy in all stages of the investigation, especially in planning an investigation.

Scaffolding as a framework for shifting learners towards autonomy

In light of the limited experience and expertise of learners doing investigations, this shift towards autonomous investigations will need to be gradual, with the teacher guiding learners through scaffolding. Gabel (2001:61) describes scaffolding as "a bridge used to build upon what learners already know to arrive at something that they do not know". In scaffolding, a teacher helps learners to focus on some aspect of the task that they did not attend to, or helps learners to integrate skills through interactive and situated feedback.

This study investigates the use of a cartoon with a prompt sheet as scaffolds in supporting learners to acquire autonomy in planning a scientific investigation. Concept cartoons, which are cartoon-style drawings showing different characters arguing about everyday situations, are designed to provoke discussion and stimulate thinking (Webb, Williams & Meiring, 2008). Cartoons have been used in a variety of ways in facilitating science learning. These include enhancing motivation in science learning (Perales-Palacios & Vilchez-Gonzalez, 2005), identifying learners' alternative ideas and thereby remedying misconceptions (Kabapinar, 2005), and provoking argumentation (Webb *et al.,* 2008). The notion of using a cartoon to stimulate investigative inquiry appears to be plausible, as a cartoon provides a context and purpose for investigating (Stephenson & Warwick, 2002). Furthermore, a concept cartoon depicts alternative frameworks of understanding which act as a stimulus for learners to explore their own ideas which may or may not be represented on the cartoon. This approach is in accordance with the constructivist view of learning, which posits that learners bring with them to the classroom a diverse set of alternative conceptions that they have developed to explain the world around them (Driver, 1983). Following this exploration of alternative ideas on a scientific phenomenon triggered by a concept cartoon, a prompt sheet with questions may be used to facilitate learners' thinking on the planning of an investigation by focusing them on the important aspects in planning (Gomes, Borges & Justi, 2008).

The notion of scaffolding which underpins this study emerged from socio-constructivist views of learning, especially Vygotsky's (1978) notion of learning in the zone of proximal development (ZPD). This zone is the difference between the child's actual development level as determined by activities that can be performed without assistance and the potential development level of the child as determined by performance of tasks under guidance of a more capable person who guides the learner through the ZPD towards a new actual development level in a gradual process of scaffolding (Van der Valk & De Jong, 2009). My study examined the use of a cartoon in conjunction with a prompt sheet as scaffolds in supporting learners to plan an investigation. Accordingly, the research was guided by the following question:

How can a cartoon accompanied by a prompt sheet support learners in planning scientific investigations?

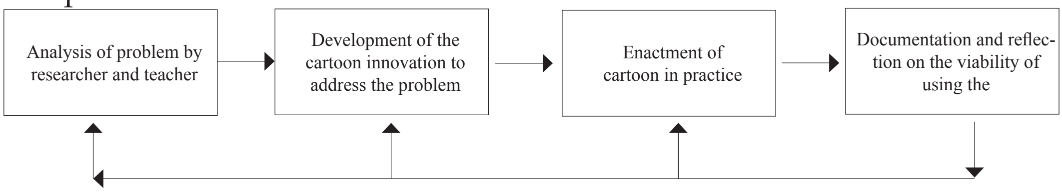
Methodology

Educational researchers, policymakers and practitioners agree that educational research is often divorced from the problems and issues of everyday teaching practice. This is a split that creates a need for new research approaches that speak directly to problems of practice (National Research Council, 2002). Such an approach is design-based research which is considered an important methodology for understanding how, when, and why educational innovations work in practice. This methodology is directed at the study of learning in context through the systematic design and study of instructional strategies and tools (Brown, 1992), leading to the refinement of innovative learning environments. I considered this methodology appropriate as it enabled me to frame my understanding of teacher experiences of using cartoons in facilitating the planning of investigations.

Reeves (2000) proposes the following design-based research stages: (a) Analysis of practical problems by researchers and practitioners, (b) development of solutions, (c) evaluation and testing of solutions in practice, and (d) documentation and reflection to produce design principles. I adopted and adapted these stages in guiding my research. This is illustrated in the diagram below (Figure 1).

Figure 1: Design-based research stages followed in study

Refinement of Problems, Solutions, and Methods in promoting learner autonomy in planning



Sample and context

This study was carried out at a high school situated in a previously designated black township in Gauteng. The school has 900 black learners. The pass rate for the Grade 12 national exit examination in the previous year was 55%. The school fee was R400 with a 40% collection rate. The teachers were all employed by the Department of Basic Education. The class size ranges between 35 and 45 learners. The school is under-resourced, and has a paucity of apparatus for science practical work.

Miss Kekana (pseudonym), the Natural Sciences teacher and her class of 42 Grade 9 learners (13-14 years) formed the focus of this study. There were 22 girls and 20 boys in this class. Grade 9 was considered significant as it is the first grade in the South African school science curriculum where learners are expected to do open investigations, which includes planning the investigation. Miss Kekana has ten years' experience in teaching Natural Sciences. She possesses a teaching degree with Natural Sciences and Mathematics as her majors.

Data collection and analysis

I collected data through classroom observations of the cartoon being used in practice by Miss Kekana and interviews with her at all stages of the research (Figure 1). I used a descriptive system of observation which enabled me to obtain a "detailed description of observed phenomena in order to explain the developing processes, and to identify generic principles by exploring specific processes" (Evertson & Green, 1986:172). A permanent record of this observation was made by video-recording the lessons. The interviews were audio-recorded. Audio from both the video-recordings and interviews were transcribed. The transcriptions were analysed using computer-aided qualitative data software, Atlas.ti. Data were coded and classified, a process that involved breaking up data into bits and bringing these bits together again in a new way (Smit, 2002). This process was largely framed by the stages of design-based research elucidated in Figure 1. In analysing the problem, I did an open coding of the data, whereby the codes were the difficulties learners encountered in planning investigations. Similarly, data collected from interviews and observations during the enactment stage of the cartoon was analysed to understand and explain the use of the cartoon in supporting learners in their planning of the investigation. At the same time, during this enactment stage, I tried to identify from the collected data difficulties which still persisted in planning. The reliability of the coding process was verified by having the transcripts analysed by two other coders. Inter-rater reliability was 87%. Where disagreement existed, it was resolved through discussion.

I developed a prompt sheet to accompany the cartoon. The prompt sheet focused on different aspects of an investigative plan, namely defining the problem, formulating a hypothesis, identifying variables, choosing the apparatus, deciding on the experimental procedure, describing how the data would be collected and recorded and, finally, how the collected data would be analysed and interpreted to address the hypothesis that was initially framed. The content validity of this sheet with regard to the prompting questions, which related to the aspects of the investigation plan, was established by having it reviewed by two researchers in science education at two South African universities. The instrument was then field-tested with a group of five Grade 9 learners from another township school. I interviewed each of the learners and asked them to identify and comment on prompting questions which were considered unclear or not readable. As a result of this feedback I reworded two questions on the prompt sheet. I scored the completed prompt sheets using a rubric that is described later. This generated quantitative data which enabled me to describe the extent to which learners were able to plan the investigation with support from the cartoon. I was then in a position to reflect upon the viability of the cartoon, and consider refinements which needed to be made to this innovation. The reliability in my scoring of the prompt sheet was confirmed by having them re-scored by a researcher in science education. There was a 90% agreement in our scoring of the sheets. The small difference in scoring was eliminated through discussion.

The Gauteng Department of Education, the principal, participating teacher and learners of the school concerned, and the parents gave consent for conducting the study and for the findings to be published. The research design was also approved by the ethics committee of the university which funded this project. Both the teacher and learner participants were informed that their participation would be voluntary and that they could withdraw at any time. However, no participant withdrew.

Findings

The findings of this study are structured according to the staged process described in Figure 1.

Stage 1: Analysis of the problem

The students in Miss Kekana's class lacked experience and expertise in planning investigations. She believed that, despite the curriculum requirement for learners to be able to plan investigations, learners needed much support in this regard. She explained this as follows:

> *They need a lot of direction. It is not that I don't have confidence in their ability, but they lack the practice of doing it. It is unreasonable to suddenly spring it upon learners that they must design an investigation on their own. They need guidelines on what is required.*

A particular problem the learners encountered in planning was the identification of variables. In targeting this problem she had given learners exercises whereby they would be given investigation problems to identify variables and formulate a hypothesis on the problem. An example of such an exercise problem was "Does the sun heat salt water and fresh water at the same rate?"

Despite her efforts, the overwhelming majority of learners found this work difficult and confusing. She explained this as follows:

> *It is very frustrating because despite spending much time on this, my learners continue to make mistakes. A problem is mainly they mix up variables. The hypothesis is not clear, and they therefore cannot know how to do it (the investigation).*

Miss Kekana was quite eager to try out a new approach with her Grade 9 class.

Stage 2: Development of a cartoon to address the problem

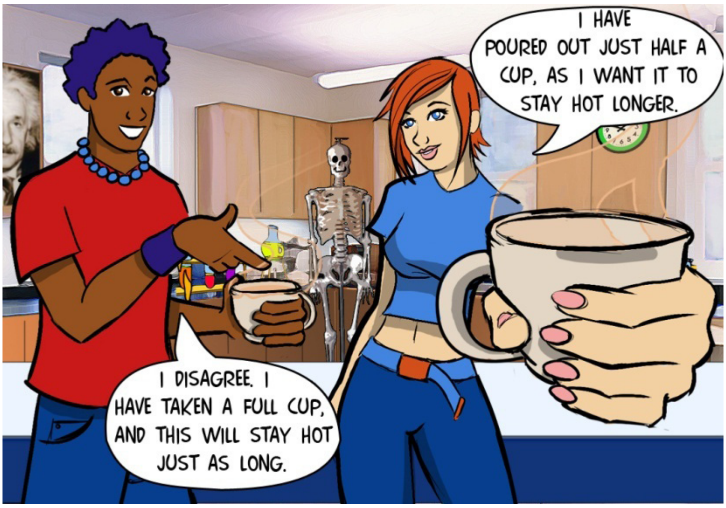
At the initial visit to the school, I learned that the next topic on Miss Kekana's work schedule was heat transfer. I presented her with the idea of using a cartoon as a support mechanism for learners in planning investigations. She was amenable to this and it was decided that a cartoon would be developed on this topic. Through discussion we agreed the cartoon would meet the following criteria:

- It would relate to some real-life experience/observation of the students.
- It would target a scientific phenomenon on the topic of heat transfer.
- It would depict alternative ideas on the scientific phenomenon.
- It would be visually appealing.
- It would use language which is accessible to students.
- It would include characters that students could relate to.

The justification for the above criteria was that the cartoons should hold the interest of the students and engage student thinking on a scientific phenomenon related to the topic. These criteria, to a large extent, agreed with the features of a concept cartoon suggested by Keogh, Naylor and Wilson (1998).

We designed a cartoon which addressed heat transfer from two liquids of different volumes. I commissioned a graphic designer to draw the cartoon based on our design. It refers to two characters, Betty and Sipho, who are in conversation over whose cup of tea, the full one or the half-full one, will cool faster on a cold day (Figure 2).

Figure 2: Cartoon on heat transfer from two liquids at a different volume



After looking at the cartoon, the learners would be asked to write a plan for this investigation. They would be supported in this by means of a prompt sheet focusing on different aspects of an investigative plan (Appendix A). I developed the prompt sheet myself. The validation process of the questions on the prompt sheet has been described in the previous section.

Stage 3: The enactment of the cartoon and prompt sheet

The 42 learners in the class were seated in groups of 6. This was the second lesson on the topic of heat transfer. In the first lesson learners became acquainted with the concept of heat, and learned that heat was a form of energy which moved from an object at higher temperature to one at a lower temperature. At the start of the lesson Miss Kekana told the learners they were going to work in groups and plan an investigation on the "cooling of full and half-full cups of tea". She handed out copies of the cartoon (Figure 2) and asked learners whether they supported Betty or Sipho in asserting which cup of tea will cool faster. The learners responded by raising their hands. Of the 42 learners, 28 agreed with Betty that her half-full cup of tea will stay hot longer, ten agreed with Sipho that his full cup of tea would stay hot just as long, and four learners were undecided and would not commit themselves. The learners then each received a prompt sheet (Appendix A). Miss Kekana asked learners to read through it and invited them to ask her questions should they not "follow what needs to be done". The learners were encouraged to engage in discussions within their groups, but were told to "come up with your own plan". Miss Kekana was confronted with many questions from learners, mainly seeking clarity on the prompting questions on the prompt sheet. They appeared to have difficulty with most questions on the sheet, especially those which related to the variables, and the data analysis and recording. It was clear the lesson had not unfolded as was planned. In the post-lesson interview Miss Kekana reflected that the learners "were very unclear about the types of variables". Although she had spent much of the lesson responding to learners on this she believed the learners still felt "uncertain of themselves". An examination of the prompt sheets confirmed this, as 35 of the 42 learners had either incorrectly identified the variables or not attempted a response. Only 10 learners had progressed to the section on writing up a step-by-step procedure. It became apparent that additional support would need to be provided for learners.

Stage 4: Refining the innovation by including additional support

I decided to develop an extended dialogue in the form of a conversation between the characters to accompany the cartoon. This dialogue (Appendix B) was envisaged to serve as a further support mechanism for learners as it would highlight key aspects being referred to in the prompt planning sheet. For example, learners would be supported in identifying control variables through a conversation taking place between the characters, where Betty suggests:

> *We will need to do two experiments. The one with half the cup of tea, and the other with the full cup of tea. We must use the same tea for both. They must be at the same starting temperature. The cups must be identical. These are called the control variables.*

In a similar manner the dialogue draws the attention of the learners to other stages in planning such as hypothesizing, recording and analysis.

Stage 5: Enacting the refined innovation

In the following lesson Miss Kekana handed out new prompt sheets together with the dialogue sheet to accompany the cartoon. Learners appeared to work more independently in responding to the prompt sheet. There were fewer questions from learners compared to the previous lesson. When learners were unsure of themselves Miss Kekana referred them to the cartoon and dialogue. She asked them to:

> *Go and read what Betty and Sipho said about independent and dependent variables again. Once you know what the dependent and independent variables are, go and enter it. That's what I want you to put in there (planning prompt sheet).*

This appeared to work well as learners who took this advice engaged more closely with the cartoon dialogue. As the learners were completing their prompt sheets, Miss Kekana moved around the class listening in on group discussions taking place. She frequently stopped and asked learners to explain an entry on their prompt sheet. When she learned that learners had made an error or omitted something in their design she asked them to "have a look at this again" or "think about what Betty and Sipho are proposing". At the end of the lesson Miss Kekana collected all prompt sheets and asked learners whether they had coped with this activity. Learners almost unanimously agreed that they had coped much better this time around. After the lesson I interviewed Miss Kekana about the innovation. She indicated that having the extended dialogue to accompany the cartoon had made a significant difference to the manner in which learners responded to the prompt sheet. When questioned on how the prompts had contributed to learning she remarked that it created an awareness of what learners needed to consider when planning:

> *Okay, I think the prompts were very good and very useful and sort of reflected a thought process that you had to go through. This sort of verbalised what you would be thinking. It explained the whole process of planning in terms of basic concepts like variables, independent analysis and so on.*

She also mentioned that the dialogue between Betty and Sipho helped engage learners in the scientific discourse and believed this may encourage learners to use scientific language when speaking. She said:

> *What was good was here were "cool" characters talking science in the science language. This helps popularise it for them (learners) and breaks the barrier of science being intimidating.*

From the completed prompt sheets it was evident that most learners were able to take their cues from the cartoon dialogue in order to respond adequately to the prompting questions. I analysed the prompt sheets for the extent to which learners were able to plan the investigation, using a rubric (Figure 3) which was an adaptation of the Science Inquiry Observation Scale applied by Villanueva and Webb (2008) in a South African study. The rubric assessed five areas in relation to planning an investigation: stating the investigation problem, formulating the hypothesis, identifying the variables; designing the experiment by outlining a step-by-step procedure and analysing and interpreting the data. The scoring is based on a four-point scale from zero to three describing a continuum extending from a situation where a learner makes no attempt at planning to a case where a learner completely meets the requirements of planning. The reliability in the scoring of the prompt sheet has been addressed in the previous section.

Figure 3: Rubric for scoring the investigation plan

Stating the investigation problem			
3 Clearly and correctly states the investigation problem.	2 Vaguely, but somewhat correctly, states the investigation problem.	1 Incorrectly states the investigation problem.	0 No attempt.
Formulating a hypothesis			
3 Hypothesis is complete, testable and addresses the stated problem.	2 Hypothesis is testable, addresses the stated problem, but needs to be more clear and concise.	1 Hypothesis is either not testable or does not connect to the stated problem.	0 No attempt.
Identifying variables			
3 Clearly defines which variable is going to be changed (independent) and which is going to be measured (dependent). All controlled variables are listed. The relationship between the variables is evident.	2 Variables are stated, but a clear relationship between the independent and dependent variables is not evident. Some controlled variables are listed.	1 Variables are not clearly stated. The relationship between the variables is unclear or not discussed.	0 No attempt.
Design the experiment			
3 Procedures are outlined in a step-by-step fashion that could be followed by anyone without additional explanations. All relevant materials are listed.	2 Procedures are outlined in a step-by-step fashion, but there may be 1 or 2 gaps that require explanation. Major materials are listed.	1 The procedures outlined are incomplete or not sequential, or the materials list is missing or incomplete.	0 No attempt.
Analysis and interpretation of data			
3 Explains correctly, clearly and coherently how the data will be analysed and interpreted.	2 Provides a plausible explanation of how the data will be analysed and interpreted, but it is not quite clear as some gaps exist in the explanation.	1 Unclearly or incorrectly explains how the data will be analysed and interpreted.	0 No attempt.

An examination of the learner responses to the prompt sheet revealed that they were, to a large extent, able to plan the investigation successfully. Quantitative data in support of this is shown in Table 1, which indicates the frequency of scoring at each level for a particular component of planning and the average score for each component.

Table 1: Learner scores per component of science investigation plan

	Level 3	Level 2	Level 1	Level 0	Average score per component of planning
Investigation problem	30	10	2	0	2.67
Hypothesis	26	8	6	2	2.38
Variables	22	10	8	2	2.24
Design of experiment	20	15	7	0	2.31
Analysis and interpretation of data	19	9	11	3	2.05

Table 1 shows that the average score for all components of planning was above 2. In terms of the rubric a score of two for a component signified that a particular response was correct but incomplete. A score of 2 is therefore considered satisfactory, and it may be concluded that learners were able to adequately plan the investigation.

Discussion and conclusion

The present study has shown that a cartoon in conjunction with an extended character dialogue and prompt sheet is a viable support mechanism for learners to plan scientific investigations. Design-based research was appropriate as it enabled me to explore an innovation in trying to address both a national and worldwide problem of learners not being able to plan scientific investigations. The initial enactment of the cartoon revealed that learners needed further scaffolding in planning. It was decided to write a dialogue between the cartoon characters Betty and Sipho. The classroom observation showed how learners, under the guidance of the teacher, took cues from the dialogue to respond to the questions on the prompt sheet. An assessment of the prompt sheets, according to a rubric, showed that learners were now able to adequately plan the investigation, indicating that this refined innovation was an effective scaffold in shifting learners towards greater autonomy in planning investigations. The need to introduce the additional scaffold in the form of the dialogue illustrates that the shift towards greater autonomy has to be a gradual progression through the ZPD.

Scaffolding also requires learners to, as soon as possible, take responsibility for the task and make important decisions on their own. This process of phasing out support is called fading and "involves the gradual removal of support until learners can manage problems on their own" (Roth, 1995, p. 242). It is therefore envisaged in the case of Miss Kekana's class that learners would eventually be able to plan their own investigations without the scaffolds of a cartoon, extended character dialogue or a prompt sheet. This issue of withdrawing support and how this affects autonomy could be investigated in another study where learners initially would be scaffolded in planning through a cartoon and then asked to plan without this support. The present study focussed on the planning stage of an investigation, as research has reported on the difficulties that learners experience in planning investigations. Future studies could explore how this innovation may be used in supporting learners through other stages of an investigation, for example, in writing a research report.

Furthermore, Miss Kekana remarked that the cartoon engaged learners in scientific discourse. This was also evident from the discussions which were taking place within the groups as learners appeared to be "borrowing" phrases from Betty and Sipho. Language is central to scientific endeavour and science learning. Scholars have suggested how the language of science with its own specific genre often serves as a barrier to the learning of science (Brown, 2004; Lemke, 1990). Learners often experience alienation from science due to the distinctive grammatical features and language structures of scientific language which are quite different from everyday language. The cartoon accompanied by the dialogue was therefore invitational to learners as they could perhaps relate to the characters depicted. The issue of scientific language could form the focus of another study on cartoons.

What is of significance in this study is the context in which this innovation was investigated, namely a disadvantaged school. Practical work requirements are not being met by a large portion of disadvantaged schools where Physical and Natural Sciences are being offered. The science experience of learners at these schools is therefore largely content based. Learners at such schools have been deprived of some of the benefits of science learning associated with practical work. This study shows that if cartoons can be developed and made available to such schools where learners have scant expertise and experience in scientific investigations, competence in planning investigations can be gradually developed.

A limitation of my study is that the research was carried out on small scale and confined to one school only. The validity of the claims that are made must therefore be tempered against this limitation. It is anticipated that future studies on the viability of a cartoon as a support mechanism for learners in planning investigations will be conducted on a larger scale involving more teachers at a diversity of schools.

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