Journal of Education, 2019
Issue 77, http://journals.ukzn.ac.za/index.php/joe doi: http://dx.doi.org/10.17159/2520-9868/i77a02

Implementation challenges influencing the efficacy of group-work tasks that require inductive or deductive reasoning during physical sciences lessons

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(Received: 12 March 2019; accepted: 2 August 2019)

Abstract

We explore the implementation challenges and efficacy of instructional strategies focussing on tasks that require learners to attempt sense-making using either inductive or deductive reasoning during group discussions. The first author collected data via participant observation of 73 Grade 10 to 12 learners whom she taught. She also used field notes, audio visual recordings, interviews, questionnaires, and learner journals. We, as the researchers, underwent the inductive cyclic process of implementation, data collection, reflection, and modification over 20 research cycles, four of which we report on here, over three years. The implementation challenges we experienced included problems related to time-consumption and classroom management, the stress related to impromptu communication, as well as the heavy demands placed on the teacher's energy levels along with some learner confusion and shortage of content knowledge. We found considerably more variability in these challenges, often negatively influencing efficacy, for the inductive instructional strategy, but a reduction in the extent of these challenges, associated with consistent efficacy, for the deductive oriented strategy.

Keywords: reasoning, groupwork, science education, induction, deduction

Introduction

Current school curricula continue to support the development of collaborative and reasoning skills, both featuring in lists of so-called valued 21st-Century skills. The initial introduction of Outcomes Based Education (OBE), with associated teacher training workshops, emphasised group work as effective in enhancing conceptual learning and skill development.

However, while group work remains a ubiquitous strategy in our classrooms, there has been much debate about the reasoning strategy to be used in group work that will promote the most effective sense-making. Some authorities (see, for example, Mahjoob, 2015) have debated whether such instruction should require learners primarily to reason inductively, that is, to draw general conclusions from specific data, or deductively, that is, to explain specific data by referring to general conclusions, while others, such as Schuster, Cobern, Adams, Undreiu, & Pleasants (2017), have provided evidence that neither approach is necessarily superior to the other. The latter support Ausubel, Novak, and Hanesian's (1968) assertion that meaningful learning can occur during reception learning when information is presented as a known product, or during discovery learning when learners are required to co-produce the information. As Schwartz, Lindgren, and Lewis (2009) have stated, "[S]ometimes it is important to explore and develop one's ideas. Sometimes it is important to receive direct guidance. The question is not which method is right; the question is what combination of methods is best for a given outcome" (p. 39).

From a teacher's perspective, what *best* means is influenced heavily by implementation feasibility. Despite its centrality in determining classroom practise, existing literature is relatively silent about the implementation challenges associated with the employment of inductive or deductive instructional strategies involving group work discussions in real classroom settings and while operating within the constraints of a highly specified curriculum accompanied by high stakes examinations. In this article, we address this issue since we seek to answer the questions: (1) What are the implementation challenges that affect the efficacy of instructional strategies involving sense-making group discussions that require learners to engage in either inductive or deductive reasoning? (2) How can the efficacy of sense-making group discussions that require learners to engage in either inductive or deductive reasoning be increased?

Conceptual framework

Given the centrality of group discussions in this research, we use collaborative cognitive load theory (CCLT; Kirschner, Sweller, Kirschner, & Zambrano, 2018) as a framework for interpretation in this study. However, we also employ more constructivist views to mitigate limitations in CCLT. These include the view that outcomes such as the development of beneficial skills, attitudes, and values are important in addition to the expansion of long-term memory (Gresalfi & Lester, 2009). We value, in particular, the development of critical thinking skills, namely "thinking that is reliant on criteria, self-correcting, sensitive to context and conducive to judgment" (Lipman, 1989, p. 8), since this is necessary for engagement in meaningful learning (Konicek-Moran & Keeley, 2015). Critical thinking may be promoted by the employment of ill-defined complex tasks, which offer significant cognitive load, and which can, potentially, provide interest and motivation, thus enhancing learning (Herman & Gomez, 2009).

The value of group discussions, according to CCLT, is in the creation of a collective working memory distributed across the collaborators (Kirschner et al., 2018). Group discussions should improve task performance provided that the task's cognitive demand is too great for each individual's working memory to cope with and that the disadvantages created by the additional extraneous cognitive load associated with collaboration is less than the advantages afforded by the collective working memory. Task features and group work management affect whether these provisions are met, so that it is unsurprising that it takes a number of years of concerted effort, self-reflection, and, preferably, mentorship, for a teacher to develop the ability to manage group discussions effectively (Johnson & Johnson, 1995). As Bennett, Hogarth, Lubben, Campbell, and Robinson (2010), concluded in a review of research on group discussions, there is "considerable uncertainty on the part of teachers as to what they are required to do to implement good practice" (p. 91).

The difference between the cognitive load offered by inductive and deductive tasks can be understood in terms of the randomness as genesis and the borrowing and reorganising principles (Kirschner et al., 2018). Borrowing information, followed by reorganising it, from sources such as a teacher, textbook, or peer, is required during deductive reasoning. This offers less cognitive load than does the hypothesis generation and testing required in inductive reasoning. Although this suggests that an inductive reasoning task will offer more cognitive load than a comparable deductive reasoning task, this does not necessarily make the inductive reasoning task less effective, since, as already mentioned, enhanced cognitive load can enhance interest, motivation, and engagement in critical thinking and group discussion can be effective in reducing cognitive load through the creation of a collective working memory. Further, learning effectiveness is dependent on which outcomes are valued.

The outcomes valued in this study are: (a) learners are interested and actively engaged in learning, (b) learners display critical thinking during the learning, (c) tasks are attainable with effort and (d) the curriculum objectives are met. These are therefore the criteria used to determine task efficacy in this study, and used, therefore, as the framework for data analysis. The value of critical thinking has already been explained. The choice of the other criteria is justified as follows. Extents of learner interest and engagement have been shown to be reliable indicators of learning effectiveness (Bransford, Brown, & Cocking, 2000). Effective learning occurs within the zone of proximal development (ZPD), which is characterised by targets being attainable with effort and collaboration (Lee & Smagorinsky, 2000). Finally, since the learners were required to pass high-stakes examinations set within a particular curriculum, it was important that the objectives of this curriculum be met.

Research approach

This study was part of a more extensive action research study that involved the promotion of critical thinking through the design of classroom materials and the use of different instructional strategies (Stott, 2008). Following Cresswell (2003), we adopted a pragmatic approach to research. We chose an action research study because of its iterative process of practice and reflection being well suited to allow for flexibility in response to the real-life problems of classroom complexity (Mc Niff & Whitehead, 2011). Both qualitative and quantitative data was collected, with a qualitative approach being dominant. We collected data through participant observation, aiming to sense the complexities of the case from within as advocated by Mc Niff and Whitehead (2011). See Stott (2008) for a detailed description of the numerous action research cycles that were conducted. We acknowledge that the particular classroom context, learner, and teacher characteristics affect which challenges will arise and the efficacy of the two approaches under various pedagogical practices as Schuster et al., (2017) have reminded us. Rich descriptions are given to allow the readers to form their own judgements about this.

The study context

A Grade 10 physical sciences class was followed through to Grade 12 and two subsequent cohorts were followed from Grade 10 to Grade 11. These 73 learners, in three classes, were heterogeneous in cultural, socio-economic, and educational background, and represented girls and boys approximately equally. The majority were not English home language speakers, although all were taught in English. All the teachers at this school have strong English competencies and teach content subjects in English (as required by national education policy) and expect the learners to read, write, and speak English in every lesson. The school has a language policy that expects learners to speak English to one another at all times for three days a week. The learners involved in this study possessed sufficient language skills to be able to participate effectively in the group discussions.

The implementation challenges exposed by this study are not those of a novice teacher struggling with classroom management and mastery of content knowledge. The first author was already an experienced teacher at the start of this study and had been implementing, reflecting on, reading about, was mentored in, and had mentored others on the management of group discussions and the creation of stimulus material for several years prior to the start of the study. She had been teaching the topics for the last 10 years and is considered a very competent teacher by her learners, head of department, principal, and the education department official responsible for science education in her district. Throughout the study, learners were given explicit instruction, informed by literature and supported by handouts and posters, in argumentation and reasoning before engagement in group discussions. Rich printed stimulus material was used to guide the group discussions. These were in the form of structured worksheets with prompts aimed at providing external conflict, while giving learners opportunities to engage in sense-making activities leading to the development of conceptual understanding.

Inductive and deductive reasoning tasks

Throughout the study, content selection and sequencing decisions were constrained by the highly specified national curriculum and the high stakes national school leaving examinations. However, the curriculum allowed for a variety of instructional strategies to be used, thereby enabling a teacher to use an inductive instructional strategy for some periods and a deductive instructional strategy for others. It is accepted that it is rare to find an instructional strategy that requires the use of only inductive or deductive learning tasks

(Prince & Felder, 2007). Consequently, it is the emphasis placed on each type of learning that is used to label the two types of instructional strategy for this article.

In keeping with Klahr's (2013) admonition to provide a clear operational definition when referring to instructional strategies, we summarise what we mean by inductive and deductive reasoning tasks in Table 1. In the inductive reasoning tasks the learners were given data and guided, by means of a worksheet, to derive a description of a concept inductively, largely during small group discussion. This is similar to a learning cycle approach that has stages of exploration-invention-application (Treagust, 2007). For example, learners were given the data of the position and velocity of a falling stone at various times in its fall. This followed a two-week period in which they had engaged with, and been taught, the concepts of position, distance, speed, and velocity. The curriculum stipulated that the learners should learn these concepts, as well as the target concept (acceleration), at this time and in the sequence used. The learners were guided using a worksheet that contained statements they had to choose between to derive the concept of acceleration.

In the deductive reasoning tasks the learners were exposed to an interesting complex conceptual problem, then taught the main concepts directly, after which they were guided to apply their learning to solve and critique the problem in multiple ways, working in groups. This is similar to the traditional strategy of "inform, make sense of through verification, and practise" (Abraham, 1998, p. 513). For example, learners were asked to discuss why an egg might not break when dropped on grass. They were then taught relevant physics concepts such as force, impulse, and momentum. This built on prior learning of kinematics from the previous year and corresponded to the content and concept sequencing stipulated in the curriculum. The learners were guided by worksheet questions about the force and impulse on, and change of momentum of, eggs that land on grass or concrete. Finally, they were required to explain what conditions would make it more or less likely for an egg to break and to support their conceptual explanations using graphs and calculations.

Table 1: Characteristics of inductive and deductive reasoning tasks used in this study

	Inductive reasoning task	Deductive reasoning task
How is the target concept introduced?	Learner derivation from data and/or information to guide reasoning, supported by teacher prompting	Teacher direct instruction
When do the learners use the guiding worksheet?	Before the teacher teaches the target concept	After the teacher has taught the target concept
What is the purpose of the guiding worksheet and sense-making group discussions?	To guide the learners to derive the target concept	To guide the learners to apply the target concept to explain a particular phenomenon
How much time was provided for engagement in the task?	As long as it took for the majority of the learners to derive the concept	As long as it took for the majority of the learners to apply the concept to explain the phenomenon

When does direct teaching occur?	After the group discussion task	Before the group discussion task
Does the teacher prompt and guide learner discussion?	Yes	Yes

Data collection cycles

Table 2 summarises some aspects of four action research cycles which are analysed and the findings presented in this article and which provide similar findings arrived at in the analysis of the full three-year study. In these four cycles, electrostatics was taught to Grade 10 and mechanics was taught to Grades 10 and 11 in two successive years. The same learners were involved in the first three of these cycles. In the first year, inductive reasoning tasks guided group discussions for the Grade 10 electrostatics and mechanics sections. In the second year, deductive reasoning tasks guided the group discussions for the Grade 10 and 11 mechanics sections.

Table 2: Four illustrative cycles out of 20 within the three years of the study

Cycle:	Grade 10 Electrostatics Y1	Grade 10 Mechanics Y1	Grade 11 Mechanics Y2	Grade 10 Mechanics Y2
Learners	23	23	23	15
Strategy	Inductive	Inductive	Deductive	Deductive
Example of one task in that topic	Induce the criterion for determining whether a substance can pick up pieces of paper or not	Induce the principle that objects of different masses will fall to the ground together if air resistance is negligible	Explain why a bullet might be stopped by a silk handkerchief but not by other fabric by applying concepts they had just been taught	Describe, and generate multiple representations for the motion of a man falling 60m onto a car and surviving
Guiding worksheet provided for this task	A partially completed mindmap summarising observations of an investigation into which substances were able to pick up pieces of paper when rubbed	Selection of the correct claim from the options of each set reveals the induced principle. Obtained from Braund et al. (2004)	Learners define taught concepts and then compare the motion of a bullet stopped by silk but not by another fabric using these concepts	Learners define taught concepts and then use these to describe and represent the man's motion

Long-term observation and triangulation and using cycles within cycles were used to ensure internal validity as suggested by Merriam (1988). The data collected consisted of 21 video recordings of group discussion lessons, 28 learner journals about their physical sciences learning experiences inside and outside of the classroom, 40 audio recorded interviews/focus group discussions, 15 different questionnaires, analyses of written work, analyses of class time usage, and daily field notes. This data was analysed iteratively throughout the action-research process as has been suggested by Mc Niff and Whitehead (2011). For example, learner journals were collected and transcribed periodically, and the perceptions revealed in them reflected on relative to the perceptions recorded in the field notes. At appropriate intervals, these perceptions were presented to learners during individual and focus-group interviews and the learners were asked to critique them.

Coding of data

In addition to the iterative data analysis during the action research cycles, data was also coded electronically using NVIVO at the end of the 3-year period. The previously listed criteria for determining the efficacy of the instructional strategies were used as broad coding categories. These criteria were subdivided into more specific coding strategies, guided by literature and/or as the need for such subdivisions became obvious during the coding process. For example, the broad coding category of engagement in critical thinking was subdivided into codes for evidence of reliance on criteria, sensitivity to context, and engagement in judgment in accordance with the definition of critical thinking given in Lipman (1989). Search queries were then run to aid the final analysis process. In the discussion on findings, claims are supported sometimes by an indication of numbers of counts recorded in the data in support of the claim. For example, (20x) refers to 20 counts or instances from the data corpus. The year in which each piece of data was collected is also indicated (Y1 = first year of the study, Y2 = second year of the study).

Findings

In the discussion below, we outline the implementation difficulties and successes experienced with the use of group discussions with the inductive and deductive oriented instructional strategies. Figures 1 and 2 are graphs of class-time usage for a cycle typical of each strategy.

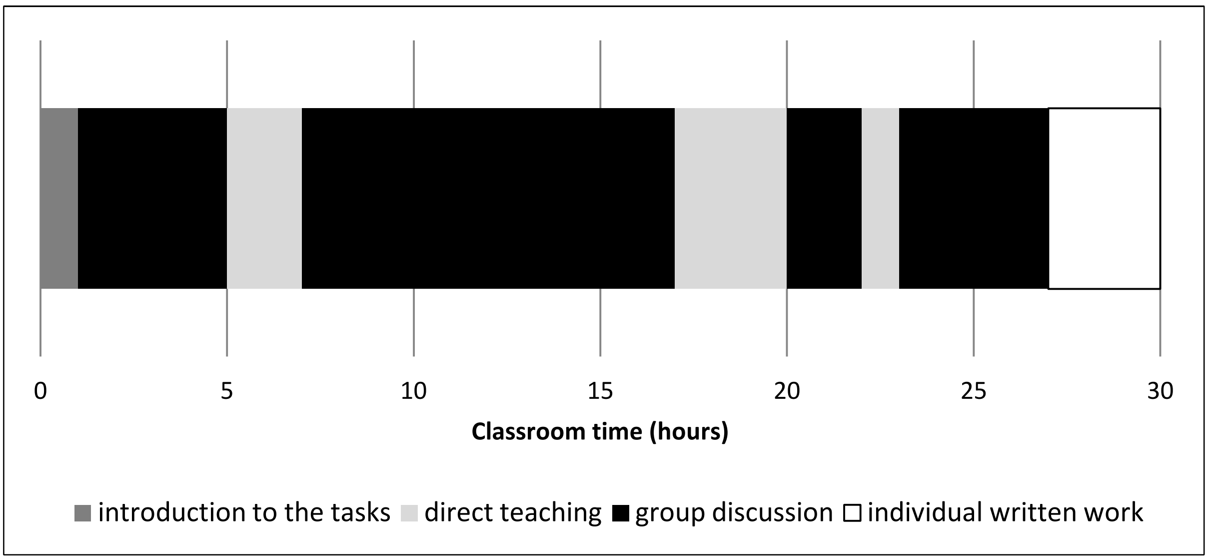

Figure 1: Class time usage in the teaching of Grade 10 mechanics (Y1) through a predominantly inductive group discussion strategy

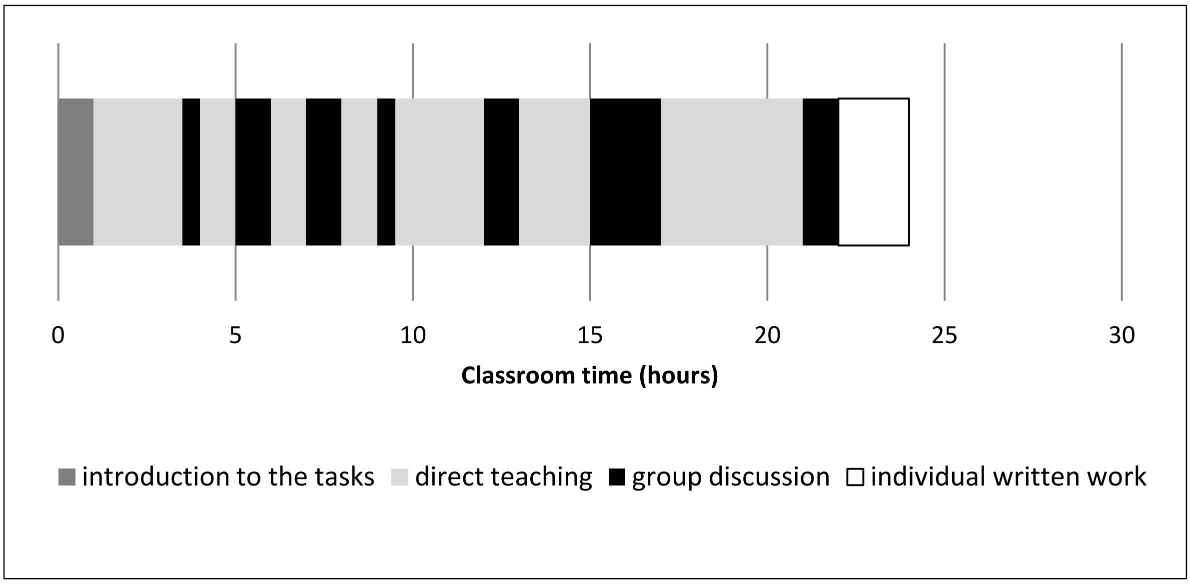

Figure 2: Class time usage in the teaching of Grade 10 mechanics (Y2), through a predominantly deductive strategy

Figure 1 shows sequentially the total time spent on the instructional activities used for the Grade 10 mechanics section in the study's first year, using a predominantly inductive instructional strategy. Figure 2 shows the teaching of Grade 10 mechanics, in the study's second year, using a predominantly deductive instructional strategy. Individual lessons were either 30 or 60 minutes in duration, with four hours timetabled for physical sciences per week. Each strategy targeted the same core content as stipulated by the curriculum document. Each of the mechanics topics using different strategies occupied over 20 hours of teaching time. Within this time there were longer activities, of, for example, six hours, and shorter activities of, for example, 1.5 hours. In the deductive strategy the longer activities were broken up into sub-activities, with instruction provided in between, as shown in Figure 2. It should be noted that in each case the teacher (first author) made every effort to utilise time effectively and efficiently. Learners were regularly given homework in each case and the decision about how much time to allocate for each activity was made according to what was reasonable as was evident from the progress the learners made during the class activities. It should also be noted that classroom activity is complex and rarely occurs as cleanly as a label may suggest. For example, during the periods labelled group discussion, the teacher would often call for the class's attention, and engage in some direct teaching for a few minutes. Similarly, during the periods labelled direct teaching, the teacher would often instruct the learners to discuss something in small groups for a few minutes.

A comparison of the two figures makes it clear that during the predominantly inductive oriented instructional strategy, considerably more time needed to be spent on group task discussion for the teacher to be satisfied that the learners had made sufficient progress to continue. This is seen in Figure 1 that illustrates longer time intervals devoted to a task without subdivision. This predominantly inductive instructional strategy to Grade 10 mechanics (Figure 1) took 30 hours. This was almost double the 16 stipulated by the curriculum. In contrast, the predominantly deductive instructional strategy (Figure 2) took 24 hours and was characterised by the longer activities being broken up into shorter sub-activities. Clearly, both these strategies can lead to conflicts if there are demands to cover the curriculum topics in a stipulated amount of time as opposed to moving on to the next topic only when the teacher is confident the majority of learners have made sense of the work.

The inductive instructional strategy

Some of the group discussions that occurred during the inductive instructional strategy were found to promote effective learning, but most were associated with so much confusion that few learners were able to learn the content effectively and many developed a dislike for topics taught in this manner. This high degree of confusion accounts largely for the long discussion times required when one is using an inductive approach. The instructional strategy was also messy and stressful to implement. To support these assertions, two cycles in the action-research process are used to illustrate the use of group discussions within the inductive instructional strategy. These cycles are Grade 10 electrostatics and one activity in Grade 10 mechanics in the first year of the study. The electrostatics cycle is used to illustrate successes, and the mechanics cycle to illustrate difficulties of group discussions used in an inductive instructional strategy.

Successes

A few learners'[1] comments (10x) during interviews suggested support for an inductive instructional strategy. For example, "It's better for us to discuss it because you understand it better if you've found it out by discussing it yourself" (Laura, Interview, Y1). Additionally, in some cases evidence from classroom interactions suggested that the learners' having to struggle through the stimulus material to derive the concepts inductively resulted in effective learning. For example, this is implied by the following extract. At the start of this 30-minute discussion lesson the class, using prior experience, had listed some materials which were able to attract pieces of paper when rubbed and others which were not. They then discussed hypotheses of why some objects, when rubbed, are able to pick up pieces of paper, and others not, as well as suggesting ways of testing these hypotheses.

> Helen said it had to do with heat released during friction, and the fact that some materials retain heat better than others. I asked her how she could test her hypothesis. After a while, she suggested that two pieces of the same material be used at different temperatures, and if heat is not the cause of the ability to pick up material, then they should behave in the same way at both temperatures. Silindile, in a different group, also suggested heat. I sent Helen to her to repeat our discussion. Sonja and Jennifer suggested texture, and then rebutted this argument, saying that then the smooth metal, plastic, and glass should behave the same, which they do not. Marike suggested that conductors could let electrons "run away." Sonja and Jennifer, in a different group, referred to conduction and asked, "Isn't wood an insulator?" I told them that it can conduct electricity, especially when wet. I asked them to explain why being a conductor or not should cause the difference. They could not answer. A few learners

[1] Informed consent was obtained from all participants included in the study.

> suggested that rubbing transferred "something" between the cloth and the plastic. Marike used the word "electrons." I then got the class's attention, asked Marike to explain what she had come up with, after which I repeated her explanation with slightly different wording. (Research Journal: Y1)

The extract above shows that effective learning was occurring according to the criteria used in this study. Throughout this section, learners displayed and reported interest in their learning. All learners participated actively. There was evidence of critical thinking in learners' discussions. For example, Sonja and Jennifer's evaluation of their hypothesis related to texture, against the criterion of observation consistency, led them to make a judgement, that is, to reject their hypothesis. The learners engaged in an effortful intellectual struggle. Further, the task was attainable and compatible with the curriculum. For example, the scientifically acceptable explanation was reached, in the extract, at least by a significant number of learners, within the 30-minute lesson. Further, learners performed well on a test on this section: of the 23, 16 scored over 70% and only 2 learners under 50%.

Difficulties

The group discussions that occurred during the inductive instructional strategy were associated with a number of implementation difficulties and, often, limited learning. Time-consumption has already been referred to. Additionally, it was a difficult, strength-sapping experience for the teacher (first author), who reported,

> I was exhausted by the noise and stress of handling multiple discussing groups simultaneously, the frustration and confusion arising from communication imperfections, and the energy demand of facilitating the slow and messy struggle of the learning processes of multiple groups, simultaneously. Further, I often had to answer questions on issues I had not prepared myself for since I had less control over what was discussed than I have during direct instruction. This made me feel insecure and I had to "think on my feet" as opposed to being able to teach according to a carefully prepared plan. I also faced decisions of how long to prolong learner struggle before providing information, how much input to provide at what times, and what to consider irrelevant discussion. Further, these decisions were compounded by pressures from multiple groups requiring my assistance, often even on the most basic level and in a repetitive manner, limited time, and classroom noise. Further, although learners were generally engaged during implementation of this instructional strategy, it appeared that often the confusion associated with this strategy was too overwhelming for the learners, so that few emerged from this confusion with a clear understanding of the concept that the activity was supposed to develop.

These claims are illustrated in the following extract, which refers to an activity from the Science Enhancement Programme's "Ideas, Evidence, and Argument in Science" material developed to promote classroom discussion (Braund et al., 2004). This task was meant to lead learners, through a series of claim choices, to see that objects of different mass will fall to the ground together if air resistance is negligible. The relevant concepts had not been taught before the task. The task was implemented at the appropriate place within the teaching sequence as stipulated by the curriculum. Learners had completed the task individually for homework the night before, and had spent about half an hour discussing their answers in groups by the time of the extract. The 24 learners were divided into five groups. The following interaction occurred between the teacher and the first group to complete the worksheet. Guided by the worksheet, they had constructed an argument that two objects of different sizes would fall together if friction were negligible. This discussion was part of the first author's attempt to make the learners see that mass, rather than size, is the important variable in this argument.

> *Teacher*: Imagine two rocks: a boulder here and a pebble there. Now they're on a slope, and we're going to push them to get them started . . . no, let's make them on a flat surface, I'm going to push each of them and make them accelerate. Now we push each of them equally . . . equal force. Are they going to accelerate equally, the boulder and the little pebble?
>
> *General*: No.
>
> *Teacher*: Why not?
>
> *Jabu*: Not the same weight.
>
> *Teacher*: Which is going to accelerate at the greater rate?
>
> *Sonja*: Boulder.
>
> *Marike*: The one you pushed the hardest.
>
> *Teacher*: No, you're pushing equally.
>
> [Noise]
>
> *Busi*: Pebble.
>
> *Teacher*: It's going to accelerate faster initially.
>
> *Marike*: But the pebble can go and sit on something and the bolder will just go over it.
>
> *Teacher*: If you have a smooth surface.
>
> *Helen*: But it's different if you drop it.
>
> *Teacher*: The principle is the same, but it's easier to think of pushing the boulders to start with. Now my point is that the question refers to how big it is, but I could change my question: What if we have a big piece of styrofoam and a small bit of gold . . . and then you push them equally, equal force on a smooth surface, which will accelerate greater?
>
> *Thandiwe*: Styrofoam.
>
> *Teacher*: Styrofoam.
>
> *Helen*: Huh?
>
> (Audio transcript, Y1)

The discussion was messy and confusing. For example, Helen's protests about falling and her interjection, "Huh?" shows confusion. I, unwittingly, added to the confusion, by saying acceleration of the lighter object would be higher initially, unintentionally implying that its acceleration would be lower than that of the heavier object later on. I also forgot that real-life observations, which is all that learners could draw on, involve other variables such as friction. For example, I said a big piece of styrofoam would accelerate at a higher rate than a small bit of gold when the same force is applied. However, in the presence of air resistance this is not necessarily so. As the discussion continued, Helen continued to protest about the situation being different during falling. She and Marike referred to size, rather than mass. This suggests that my attempt to show that mass, rather than size, was the significant variable in affecting acceleration, was ineffective. Further, this extract is only part of the interaction I underwent with only one of the five groups. Discussions with the other four were similar.

In addition to the implementation difficulties highlighted above, this discussion cannot be considered effective in terms of the criteria used in this study. Although the learners appeared to show some interest in the discussion initially, this waned as they got lost in the confusion generated, and their interest was later replaced with a general dislike of the topic. Although learners were actively involved in effortful learning, which did involve critical thinking, the end point of the task was not obtainable and did not lead to the learning required by the curriculum objectives for the majority of learners. The learners' dislike of mechanics was evidenced in many negative comments recorded in interviews (26x), as well as comments overheard from learners to this effect throughout the first year, and none to the contrary. This dislike of mechanics seems to have resulted from the instructional strategy rather than the topic itself, suggested by a high degree of positive interest and enjoyment (86x) reported in their journals the following year when a deductive instructional strategy was employed for mechanics.

The lack of task attainability and poor correspondence to the curriculum objectives are evidenced by the observation that most learners did not learn the desired concept effectively. Even though over an hour was spent discussing this concept, and it was revised later, in the examination only six learners out of the 23 could give this argument correctly. The learners' poor learning during engagement with most of the inductive reasoning tasks can be understood in terms of the learners' poor generalisation and pattern-searching skills, and their limited working memory capacity that resulted in their being unable to derive the required concepts during the inductive facilitated discussion in which they were engaging.

The extract also shows evidence that the learners were engaging in an intellectual struggle that involved critical thinking. For example, Helen's frequent protests suggest that she was undergoing an intellectual struggle. Further, Helen and Marike's frequent rebuttals of my explanation, such as "but it's different if you drop it," and "but the pebble can go and sit on something" suggest that they were undergoing critical thinking to some extent. This critical thinking was tentative and had little metacognitive character. This can be seen in the learners' lack of self-direction, as shown by their heavy dependence on the teacher, as well as the vagueness of their remarks.

The lack of effective learning, despite learners engaging in critical thinking, can be explained by the learning being too confusing and overwhelming to be productive. For example, referring to the mechanics section that was taught using an inductive instructional strategy, Tim remarked, "It was like all thrown at me and I had to take it all in big chunks" (Tim, Journal, Y1). He also admitted, "We got into dead-ends, most of us were off track."

The deductive instructional strategy

In the deductive instructional strategy, direct instruction was followed by sense-making group discussions aimed at enabling learners to apply learning to solve a problem deductively. We found every instance of group discussion used in this instructional strategy effective in terms of this study. However, most of the same implementation challenges experienced for group discussions used in the inductive oriented strategy were experienced in the deductive oriented strategy, although to a lesser extent.

Two cycles within the action-research process are used to illustrate and support assertions made about the efficacy of the deductive instructional strategy: Year 2 Grade 10 introductory mechanics (see Figure 2) and Year 2 Grade 11 mechanics. As can be seen from Figure 2, roughly week-long direct instruction of subsections of the syllabus was followed by hour-long group discussions. In these, learners were required to make sense of concepts they had learned throughout the week in order to use them in explaining a real-life interesting phenomenon. These group discussions were guided by worksheets which the learners answered individually, in writing, for homework, during the course of the week. This strategy was associated with decreased implementation difficulties relative to the inductive instructional strategy. It was also effective in terms of this study, as discussed below.

Successes

Learners were interested in their learning during both these cycles. Numerous interview and journal comments (158x) similar to the following testify to this: "I'm really enjoying Science this year" (Phindile, Journal, Y2), and "Before I wasn't really interested in science, but now I'm so interested, and even just in normal life I just mention something to do with science" (Agnes, Interview, Y2). This application to life extended to discussions on the sports field: "I also spoke about it practically with Gert and Seth when we were playing cricket yesterday (the momentum when we catch the ball)" (Cole, Journal, Y2). In a questionnaire, 86% of the 57 learners questioned reported that they enjoyed a deductive instructional strategy. Evidence of active learning (173x) is given in audio-recorded footage of discussion sessions, and comments given by learners and their parents, e.g. "She would discuss it at the supper table'" (Parent, Personal Communication, Y2) and "I would think about it before I went to sleep" (Sofia, Interview, Y2). Learners displayed critical thinking during the group discussion times after initial direct instruction, as illustrated in the extract below. According to the students, learning throughout the section was characterised by effort (102x). The discussion below also illustrates this. Finally, the tasks used in this instructional strategy were also found to be attainable and compatible with the curriculum in that 30 of the 39 written explanations of the discussed phenomena, submitted at the end of the section, implied a deep or reasonably deep understanding of the associated physics. Another eight of the answers were satisfactory, with 1 learner not performing acceptably. In a questionnaire, 68% of learners reported that they learned effectively from a deductive instructional strategy. Numerous learner journal entries (106x), following discussions in which groups applied conceptual knowledge deductively to a situation, reported effective learning. A typical example is, “Explaining things to people helps to sort out the logic in my mind” (Sofia, Journal, Y2).

In the extract given below, a group of Grade 11 learners were discussing why a silk handkerchief might stop a bullet. Critical thinking can be seen in the learners’ judgements, supported by reasons, and their use of questions to self-direct learning.

> *Thandiwe*: When they meet.
>
> *Marika*: That makes it slow down.
>
> *Thandiwe*: That compression force . . . does it make it a Newton-3 thingy?
>
> *Marika*: No, the same force that the bullet hits the person with, the person pushes back with and this slows the bullet down, I think.
>
> *Thandiwe*: Well, yes, it does, because if it didn’t, the bullet would have continued through.
>
> *Marika*: So it does.
>
> *Lauren*: But what I think is, if it’s a jersey, how come doesn’t it stop the bullet?
>
> [Pause.]
>
> *Lauren*: Because N-3 applies in the case of a jersey too.
>
> *Thandiwe*: Doesn’t it . . . friction helps it to . . .
>
> (Audio transcript: 25/01/Y2)

Before this session the learners had been taught, directly, the mechanics concepts they are using in their sense-making discussion. At this point in the discussion, the teacher explained that friction from a surface acts parallel to the surface, and so there would need to be a component of the bullet’s motion parallel to the surface for friction to play a role in slowing it. Thandiwe responded that the indentation the bullet would make allows for this, showing critical thinking while trying to construct her own understanding of the situation, rather than just accepting the teacher’s rebuttal as coming from an unquestionable authority.

The success of discussions such as this one is seen to be closely linked to the fact that the learners were able to use deductive reasoning as they applied their general learning to this specific incident. As they did so, they made sense of their learning, and so developed understanding. If the above discussion had been attempted before direct teaching of the concepts, it is unlikely that learners would have been able to engage effectively in critical discourse, since it is unlikely that they would have been in possession of the knowledge needed to do so. Relative to the inductive instructional strategy, the deductive instructional strategy was less stressful for the teacher. When she used an inductive instructional strategy, she had to prompt and discipline the learners continually in order to keep them on task. In contrast, during the deductive instructional strategy, learners required her input only occasionally. This was with the exception of two groups in the Grade 11 mechanics class, who required almost constant help. This reduced need for her input is also thought to have reduced learners' drifting off task as they waited for the teacher to finish helping other groups.

Difficulties

Although all the instances of use of group discussions within the deductive instructional strategy were found to be effective in terms of this study, it did also have difficulties associated with it. These include time-consumption and implementation challenges. This extract illustrates the messiness, frustration, struggle, and communication difficulties the learners often experienced: "I thought the egg doesn't decelerate when it hits the ground. This made it difficult for me to understand most of my group's discussion. By the end of the lesson I had a headache!" (Busi, Journal, Y2).

The discussion regarding a silk handkerchief stopping a bullet referred to earlier was clearly far messier than the kind of interaction usual in a traditional classroom. This messiness can be seen, however, as a positive indication of effective learning occurring as long as the learner does emerge from this messiness to understanding as Bransford et al., (2000) have made clear. The high scores achieved on the target explanatory tasks and the positive remarks about attainability of the tasks suggest that this was so for a large number of learners for this strategy.

Discussion

In this article we have described and analysed four of the 20 action research cycles over a 3-year period which have informed our developing understanding that group discussions within both the inductive and deductive instructional strategies can lead to effective learning as defined in this study, although they are associated with implementation challenges. We make three main claims which arise from this study.

(1) Effective use of group discussions can be time-consuming, messy, and demanding on the teacher's energy, and her or his classroom management and communication skills, and requires the teacher to have a very good understanding of the content, and an ability to think on her or his feet. These demands seem to be even greater when the teacher tries to implement an effective group discussion focusing on the use of inductive reasoning than when focusing on the use of deductive reasoning.
(2) Teaching with an emphasis on inductive strategies is more likely to result in learning with understanding in cases where few concepts unfamiliar to the learners are involved, and the teaching does not extend beyond a single contact session.
(3) Direct instruction, followed by group discussions in which learners are guided to use deductive reasoning primarily, appears to be an effective instructional strategy to promote learning with understanding.

Group discussions are difficult to implement, particularly for inductive tasks

The finding that the discussion process required effortful involvement by the teacher is consistent with assertions such as those made by Johnson and Johnson (1995), that group discussions cannot be effective unless the teacher is actively involved during the discussion process. This can be understood in terms of the complexity of the tasks being such that success requires the learners to borrow from the teacher's more extensive knowledge as well as to use the teacher's working memory as part of the group's collective working memory as they engage in the cognitive process of borrowing and reorganising (Kirschner et al., 2018). The finding that implementation challenges were reduced in the deductive instructional strategy relative to the inductive instructional strategy can be explained in terms of the reduced cognitive load associated with the deductive tasks, as discussed below. Direct instruction, which the teacher provided before the learners engaged deductively with the task, lends itself to greater structure and clarity than inductive exploration does (Rosenshine, 2009). The finding that inductive instructional strategies are more time-consuming and more likely to lead to learning in unintended directions, than deductive instructional strategies, echoes Driver's (1983) seminal work.

Inductive discussions should be short and involve few new concepts

A marked difference was noticed in the effectiveness of the mechanics and electrostatics group discussions used to illustrate an inductively oriented instructional strategy. The less effective mechanics task required learners to use numerous abstract concepts they had not yet mastered, such as acceleration, force, weight, mass, size, density, and ratios of weight to mass to derive an argument which did not match common experience, that is, that a light and a heavy object would fall together in a vacuum. This was done over an extended period of time, and over many contact sessions. In contrast, the more effective electrostatics task required learners to use fewer, and more familiar, concepts, such as electrical conductance, friction, heat, and texture, to derive an explanation for a phenomenon most of them had observed, that is, the ability or inability of various substances to pick up pieces of paper when rubbed. This was done in a single contact session lasting half an hour.

This is consistent with views that a deductive instructional strategy offers less cognitive load since it relies largely on the load-sharing "borrowing and reorganising" principle, whereas an inductive instructional strategy relies heavily on the very cognitively challenging "randomness as genesis" principle (Kirschner et al., 2018, p. 5). It is also consistent with findings that group discussions are less likely to lead to the development of understanding when learners hold incorrect or incomplete prior knowledge (Bennett et al., 2010). Proponents of constructivist pedagogy generally cite enhanced motivation as one of the strengths of exploratory activities (Herman & Gomez, 2009). We found that group discussions decreased motivation when learners were required to derive numerous unfamiliar concepts inductively over an extended period.

Direct instruction followed by deductive discussion is effective

During the deductive group discussions the learners were interested, actively involved, and they displayed critical thinking skills as they engaged effortfully with the tasks, and almost all the learners managed to achieve the minimum requirements for the task and learn what was required of them according to the curriculum objectives. The collective working memory of the learners appears to have been sufficiently large to cope with the cognitive demands of the task, allowing the learners to engage in critical discourse, resulting in what Konicek-Moran and Keeley (2015) would regard as meaningful learning having occurred.

Limitations, implications and suggestions for further study

The findings of this study may be limited to typical high school contexts in which novice learners are expected to work through a content-rich curriculum in a limited space of time to prepare for high-stakes examinations. Also, these classes were smaller in size and had higher English language skills than is the case in most South African schools, suggesting that more typical South African classes would experience the described difficulties to a greater degree as Ramnarain, Nampota, and Schuster (2016) found. This would be relevant throughout the world wherever students have poor language skills in the language of teaching and learning. It is also expected that the more limited the conceptual understanding of the teacher, or the less skilled at handling the kinds of difficulties discussed, the more acutely these difficulties would be experienced. This has some correspondence to Klahr's (2009) caution that the feasibility of implementation of an instructional strategy depends on teacher competence and teaching context.

It would be interesting to explore the challenges and gains that more typically traditional teachers, entrenched in lecture-style pedagogy as Ramnarain and Schuster (2014) have explored, might experience as they shift to a greater use of group discussions involving reasoning tasks. Our findings suggest that unless this pedagogical shift focuses predominantly on group discussion within a deductive oriented instructional strategy, such teachers and their students would probably be disillusioned by the experience, as were many South African teachers following their attempts to implement OBE in their classrooms as is documented by a number of sources, such as Schweisfurth (2013).

Conclusion

While we disagree with the view held largely by disillusioned teachers that effective use of group discussions is not feasible in what they think of as a real classroom, we do acknowledge that it is difficult. This is particularly so when one is using group discussions within an inductive instructional strategy and particularly when curriculum pressure is great. We believe that we have shown that group discussions using both inductive and deductive instructional strategies can work effectively if implemented with careful consideration when the concepts to be taught and the classroom context are taken into account.

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