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Teaching and learning implications on group experiments and teacher demonstrations to teaching of process skills in biology: A case of two Namibian secondary schools

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The article reports on the teaching and learning implications of teacher demonstrations and group experiments for practical work in biology at Namibian secondary schools. The study involved three teachers and two secondary school centers. Data on were collected using a video observation quoting schedule. The findings showed that teacher demonstrations in biology provide fewer opportunities (if any) to students for acquiring intended process skills (practical skills) compared to group experiments. Teacher demonstrations were found to develop a few process skills, such as making observations, recording observed results, and writing conclusions, whereas group experiments allowed students to acquire variety of process skills. Teacher demonstrations provided little opportunity to students to discuss and negotiate subject content knowledge at the intermental plane.

Keywords: teacher demonstrations, group experiments, process skills, practical work, practical skills, intermental plane, knowledge constructions, learner-centered approach

Introduction

Namibian science curriculum requires Grades 11 and 12 biology students to acquire learning-process and investigative skills. They are expected to conduct practical activities and take a practical examination at the end of secondary school. However, most secondary schools in Namibia lack well maintained, modern laboratories and other resources. Some laboratories are too small, and some have inadequate student workstations. More secondary schools in Namibia offer teacher demonstrations than group-experiment activities because they lack laboratory resources.

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In this article, *practical work* refers to laboratory activities that include lecturing, group experiments, and teacher demonstrations that involve students in handling and observing real objects and materials (Millar, Le Marechal, and Tiberghien, 1999). *Teacher demonstrations* in this study were performed by the teacher with the assistance of students. The teacher called a few students to the front of class and then told them what to do. According to the revised *National Curriculum Statement Grades R–9 (Schools)* published by the Department of Education (DOE) of South Africa (2002). Since 2009 split by Department of Basic Education and Department of Higher Education and Training.

> *The term "process skills" refers to the learner's cognitive activity of creating meaning and structure from new information and experiences. Examples of process skills include observing, making measurement, classifying data, making inferences and formulating questions for investigation. The term should not be understood as referring to the manipulative skills which are a small subset of process skills.… From the teaching point of view, process skills can be seen as building blocks from which suitable science tasks are constructed.… From the learning point of view, process skills are an important and necessary means by which the learner engages with the world and gains intellectual control of it through the formation of concepts.*
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> —National Curriculum Statement Grades R–9 (Schools) (2002, p. 13)

Ogunniyi and Mikalsen (2004) have a view similar to that of the South African DOE, regarding process skills as "intellectual tools or strategies used for performing cognitive tasks.… Process skills entail the use of concepts, and the manipulation of concepts involves process skills" (p. 152). They argue that process skills can be inferred only from actions such as verbal or written responses, even in situations in which such skills have not been deliberately taught. To them, "it cannot be assumed that there is a one-to-one correspondence between a demonstrated process skill and a singular cognitive activity in that the constituent elements of such a skill cannot be reduced to classes of experience"(p. 153). In Namibia the Namibia Senior Secondary Certificate (NSSC) biology syllabus lists five process skills students should develop. Process skills are grouped into categories, from the lowest to the highest level of difficulty (Skill 1 is the lowest level and Skill 5 the highest; Table 1).

The aims of practical work are often related to the nature of learning outcomes (Gott and Duggan, 1996; Hodson, 1996; Pella, 1969; White, 2003), including investigative and process skills. The development of these skills, therefore, is related to the types of practical activities performed for learning purposes. Such activities are more meaningful to students when teachers provide appropriate opportunities to students to handle the apparatus and materials, to observe events, to handle experimental results, and draw conclusions from their observations (Bennett and Kennedy, 2001; Roberts and Gott, 2000; White, 2003). Practical activities promote process-skills acquisition.

Theoretical Underpinnings

The term *constructivist teaching* is commonly used in the teaching and learning context to describe a method of instruction in which the teacher creates opportunities that allow students to construct new understandings for themselves at individual and social levels, understanding biological concepts in our particular case. In constructivist teaching the teacher assists students (Brooks and Brooks, 1993; Duit and Treagust, 1998) in mediating meaning at the intermental plane in the classroom (Hodson and Hodson, 1998b. The teacher becomes a guide, provocateur, creator of opportunity, and codeveloper of understanding for students (Windschitl, 1999). Therefore, instructional practices of constructivist teachers assist students in constructing new understanding, including via acquisition of process skills. The research questions posed in this study are as follows:

- Are the skills addressed in group experiments and teacher demonstrations the intended process skills?
- What teaching and learning implications do group experiments and teacher demonstrations have for preparing students for practical examination?

Table 1: Process (Experimental and Investigative) Skills

Skill	Component
Skill 1	Follow sequence of instructions; Use appropriate techniques; Handle apparatus and material competently; Have due regard for safety
Skill 2	Make and record estimates accurately; Make and record observations accurately; Make and record measurements accurately.
Skill 3	Handle experimental observations and data; Process experimental observations and data; Deal with anomalous or inconsistent results.
Skill 4	Apply scientific knowledge and understanding to make interpretation from practical observations and data; Draw appropriate conclusions from practical observations and data.
Skill 5	Plan, design investigations; Carry out investigations; Suggest modifications in the light of experience.

Methodology

Research Design

Given the nature of laboratory teaching and learning, a descriptive, in-depth qualitative design (Denzin and Lincoln, 2000) seemed appropriate for exploring the dynamic nature of laboratory discourse between teacher and students and for understanding the nature of practical-work activities in a school setting (Patton, 1990; Cohen, Manion, and Morrison, 2000). The sample was selected carefully, and although the findings are transferable (Patton, 1990) to schools with similar situations, the purpose was not to generalize the findings. Two urban schools (A and B) in two suburbs of different socioeconomic levels were selected to explore differences between their biology laboratories. A purposive sampling method was used, for the richness and depth of information it would yield (Creswell, 2006; Stake, 2000), rather than an overview of many participants. This sampling method increased the quality of information gathered (Bless and Higson-Smith, 2000; McMillan and Schumacher, 1997). Three biology teachers were selected who met the following criteria: (a) teaching at a school well or fairly well equipped with laboratory materials; (b) having appropriate command of their subject and teaching for three or more years at the same school; (c) employed at schools with good student performances (i.e., average grade of C or above in biology examinations); and (d) willing to participate in the study.

Data were collected using videotaped observations and analyzed to determine whether intended process skills were addressed during instruction. The video observation quoting schedules were adapted from the schedules of Mortimer and Scott (2000, 2003) on classroom discourses and of Millar et al. (1999) on laboratory work. Observations included three aspects of classroom discourse: the nature of intervention, the form of utterances, and actions in the flow of the discourse as carried out by teacher and students. Data quality was ensured by the "honesty, depth, richness and scope of the data, the participant approach, the extent of triangulation and the disinterestedness or objectivity of the researcher" (Cohen, Manion, and Morrison, 2000, p. 105).

School and Teacher Profiles

School A

School A is a high school established to educate German-speaking children during the colonial era in Namibia. A typical high school in Namibia consists of Grades 8–12, that is, junior and senior secondary levels are combined in most high schools. The school is in one of the former white suburbs, Lutwein, in the Windhoek Educational Region. The school is within reach of a shopping center where the teacher could easily buy science equipment and materials. Since Namibian independence in 1990, the school's population profile has changed tremendously and now consists of children of all ethnicities.

Figure 1: Biology Laboratory A at School A

School A has well-developed learning facilities and resources, such as the science laboratory, library, laboratory equipment, resource books, and textbooks. The teachers are well trained academically, and most of them have more than 3 years of teaching experience. In addition, the school has a history of performing well in Grade 12 examinations. Figure 1 shows a biology laboratory well equipped with a variety of equipment and modern gas and water taps at student workstations.

The laboratory has different types of light microscopes and biviewers in the cupboards next to each workstation. The shelves on the wall hold resource books, paraffin lamps, and extra Petri dishes. The laboratory is used only for laboratory purposes and not other classes.

Christie,* a biology teacher at School A, had taught different grades over the years. She taught Life Science to some Grade 10 classes as well as to two Grade 12 classes in the laboratory depicted in Figure 1.

Jarijo, also a biology teacher at School A, taught biology to some Grade 11 classes and most junior classes in the laboratory in Figure 2 (shown with no students present).

The laboratory in Figure 2 has the same setup as the laboratory in Figure 1. Although not as well equipped as the laboratory in Figure 1, this laboratory has water and gas taps and enough equipment to carry out practical activities and not just demonstrations. Figure 2 shows students' collections of insects and other organisms as well as posters on the wall at the back of the classroom. On the wall cupboards are illustrations of projects by students.

Christie and Jarijo gave their biology students practical work in small groups (group experiments).

Figure 2: Biology Laboratory B at School A

School B

School B, established to educate black children, is situated in a suburb, Riverside, on the boundaries of the city of Windhoek and within the Windhoek Educational Region. Most people here have modest means. The school accommodates children from middle-class families and is multiethnic. This school is well managed and has a good building infrastructure. The teachers are academically well trained and are experienced teachers. In addition, the school has a history of students performing well, with grades ranging from As to Cs in Grade 12.

The laboratory setup at School B is different from School A's. There are no fixed workstations for learners as was the case at School A. Instead, there are only long benches with no gas or water taps. The laboratory is also used as a classroom for biology lectures. The laboratory does have small storerooms attached to it.

Lena, the biology teacher at School B, conducted teacher demonstrations in

* Teachers and other participants in this study have been given false names.

this laboratory, rather than the small-group experiments held in School A's laboratories A and B.

At School A, two biology teachers fictitiously named Christie and Jarijo and School B, Lena participated in the study. Christie and Jarijo exposed their students to biology practical work small group (group-experiments) while Lena conducted teacher-demonstrations regularly.

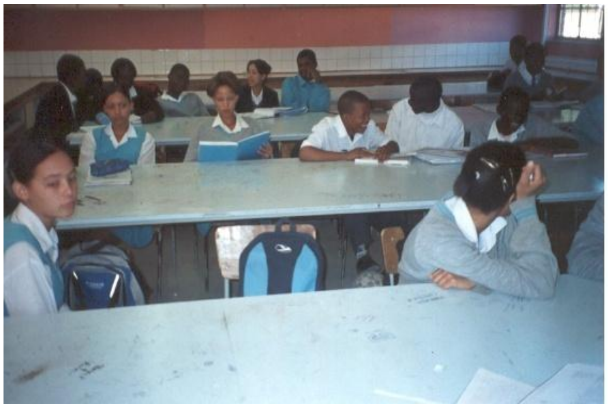

Figure 3: Biology Laboratory at School B

Christie

At the time of data gathering Christie has more than 20 years' teaching experience, all at School A. Her seniority puts her in an advantaged position for practical work. The classroom where Christie teaches theory has an amphitheater design and a teacher workstation at the front of the class. Student desks are arranged in ascending tiers, allowing students' unobstructed views of the teacher and demonstrations.

The laboratory, on the other hand, has a different sitting structure, with five rows of fixed laboratory benches on the same level and typical, tall laboratory chairs. The teacher workstation is at a higher level than the student benches. When standing at her workstation, Christie has a bird's-eye view over the laboratory. Students sit in small groups in the laboratory with no apparent pattern. Some of the groups are large, up to eight students; smaller groups had up to four students. Students sit with friends or with peers with whom they could easily work. Some groups seem to prefer to communicate in English, Afrikaans, or German. However, now and then I hear students speaking in local languages such as Oshiwambo and Otjiherero. Most of the discussions in small groups take place in these languages rather than in English, which is the medium of instruction in Namibia.

At School A students are extremely disciplined and are hardly ever late to classes. I observe students entering the laboratory and starting to work on practical tasks specified in the laboratory manuals, which had been developed by the biology teachers at School A. Students go into the laboratory after Christie has lectured on the theory under discussion. There are no separate classes for prepractical discussions; these discussions are conducted by Christie alongside the theory lessons.

Christie offers a range of practical activities. At the time of data gathering, lessons are on food testing and testing a leaf for the presence of starch. In most of the sessions I observe, Christie minimizes her role; she maintains the overall safety in the laboratory, distributes materials and apparatus, and provides assistance where needed. Christie moves around regularly from one group to another and warns students to beware the flames from the gas taps and the

Bunsen burners. During laboratory exercises she mostly operates in the background, providing assistance to students. After a series of practical tasks, however, she arranges discussion classes to discuss essential issues.

Jarijo

Jarijo is a young, inexperienced biology teacher with 3 years of teaching experience. Christie had mentored Jarijo, and so her teaching style resembles Christie's. One difference in teaching style is that Jarijo does not arrange discussion classes after practical activities.

Jarijo's biology classroom for teaching theory is on one level, unlike Christie's tiered classroom. Jarijo's biology laboratory, like Christie's, has long benches and typical, tall laboratory chairs for students. The teacher's workstation is fixed at the front of the laboratory. Long built-in benches line the walls, and five long benches are fixed in the middle of the laboratory. Most of the apparatus and materials are kept in Christie's biology laboratory, and other teachers borrow them when needed.

Jarijo is concerned with applying knowledge. What matters most to her is enabling students to put knowledge they have gained into practice, that is, by doing practical work. In the laboratory Jarijo focuses on illustrating the scientific concepts she taught in the theory lesson. It is evident from direct classroom observations that students are mainly involved in such practical activities: observing color changes when starch or simple sugars are present in food samples or detecting the starch present in a living leaf.

Lena

At the time of data gathering Lena has 8 years' experience teaching biology at School B. The only biology teacher at school B, she gives the theory lectures and supervises the practical-work sessions in the biology laboratory. The biology laboratory benches are not fixed in the normal way.. Cupboards are attached to the walls, and they have seven laboratory basins atop them. Taps for gas and water are available but nonfunctional. The walls of the biology laboratory are bare, with no relevant posters or models as in Christie's and Jarijo's laboratories.

The teacher's workstation is fixed in the front part of the laboratory and a chalkboard is on the wall behind it. The teacher's workstation sits a little higher than the student benches. The laboratory is crowded and students and the teacher have little space to move around freely. Up to 39 students are in the laboratory.

Unlike the students at School A, students at school B are highly undisciplined. After entering the laboratory, students take their time settling down and Lena struggles to maintain order. Students seem uninterested in practical tasks and most discussions are off task. Now and then I hear Lena silencing them: "Keep quiet. You there, go sit down. We want to start with the practical work." One day students took 3 minutes to settle down before instruction could begin.

Results, Findings, and Discussion

The three biology teachers (Christie, Jarijo, and Lena) exposed their students to practical work in three different ways: group experiments, teacher demonstrations, and lectures. Teachers at School A (Christie and Jarijo) mainly used lectures and group experiments, and the teacher at School B (Lena) used lectures and teacher demonstrations.

a) Group Experiments

Students in group experiments at School A carried out practical activities that dealt with starch, performing tests for glucose, sucrose, proteins, and fats and a general test for food samples of their own such as apples. All practical activities are arranged in a similar way at School A and focus on developing the process skills in Table 2.

Table 2: Intended and Implemented Practical Skills Performed by Students in Group Experiments

	Intended practical skill	**Frequency of implemented practical skill**
Skill 1	a) Follow sequence of instructions; b) Use appropriate techniques; c) Handle apparatus and materials competently; d) Have regard for safety.	a) 2/3 of time b) not applicable c) 2/3 of time d) ¾ of the time
Skill 2	a) Make and record estimates; b) Make and record observations; c) Make and record measurements accurately.	a) not observed b) always c) always
Skill 3	a) Handle and process experimental observations; b) Handle and process experimental data; c) Deal with anomalous or inconsistent results.	a) answer questions (mentally) b) not applicable c) not applicable
Skill 4	a) Apply scientific knowledge and understanding to make interpretation from practical observations and data; b) Apply scientific knowledge and understanding to draw appropriate conclusions from practical observations and data.	a) always b) not applicable
Skill 5	a) Plan investigations; b) Design investigations; c) Carry out investigations; d) Suggest modifications in the light of experience.	a) not applicable b) not applicable c) always d) always

Table 2 shows how the practical tasks offered opportunities to students to develop process skills at different levels of difficulty. Looking at the frequency of implementation of the process skills, it is clearly observable that, for example, Skill 1 and Skill 2 were attended to in each applicable practical activity, and all the applicable intended process skills are implemented at least some of the time by students. Experimental activities did not provide for the development of some skills, which are noted as not applicable: Skill 1b, Skill 2e, Skill 3i and j, Skill 4l, and Skill 5m and n. Group experiments gave students opportunity to explore, understand, and act on the ideas stated in the theory lessons.

The following episodes are examples of actual student interactions in different lessons.

Episode 1: Test leaf for starch

In Episode 1 students work in the biology laboratory under the supervision of Jarijo. The group experiment tests leaves for the presence of starch. Students use laboratory manuals to complete their practical activity. They interact with one another and the teacher while investigating the subject content to complete the laboratory task. This group consists of three students.

Mara *Where are the matches?*
Judy *Here.*
Jarijo *Start with the hot water bath.*
Mara *The stick? [Referring to the leaf.]*
Judy *No.*
David *Are you scared?*
Judy *Ooouugh…. [Lights the Bunsen burner.] Yes I am very scared. How can I light up this thing?*
Jarijo *Do you know exactly what you supposed to do?*
Judy *Yeah.*
David *Give it to me. [Takes matches from Judy.]*
Judy *OK, take it.*
Mara *Open the gas tap … slowly. Come on, open.*
Judy *Do you know what you supposed to do? [Referring to Jarijo's instructions.]*
David *Yeah.*
Mara *Come on. [The gas makes a puff! sound, and she closes the gas tap immediately.]*
Judy *You see. [Laughing.]*
David *[Opens the gas tap slowly and lights the Bunsen Burner with a match while controlling the tap.] Because you can't do it on your own.*
Judy *It must actually be blue light.*
Mara *Control it here.*
Judy *Ooouugh [finally the flame becomes blue], waaagh. Yes, now what will we do next? [Holds the leaf in her hand.]*
David *We must boil it.*
Judy *Put it in here.*
Mara *Let me read. We must draw it first.*

In Episode 1 the students interact with one another following the communication pattern I-R-E-R-E-R-E chain, where I represents initiation, R represents response, and E represents evaluation of the response. Judy dominates the discussion; she responds to others nine times while Mara and David respond five times. Students respond orally or physically. For example, David asks Judy whether she is scared (oral communication), and Judy in another incident, for example, responded to David's "Give it to me" by handing him the matches (both oral and physical communication). The students' discussion focuses on two issues: handling of materials and performance of skills such as using the Bunsen burner and controlling its gas tap. Thus, much of their talk centers on the use and handling of materials and scientific equipment. The only observation the students make that is relevant to the lesson is the one in which they refer to the blue light of the Bunsen burner's flame. Distribution of duties is not explicitly discussed, but students appear to know their responsibilities within the group. None need to be reminded of duties they are neglecting. Every student contributes, taking it upon herself or himself to carry out a duty toward completion of the task.

Episode 2: Test leaf for starch

Episode 2 occurs in the middle of a lesson in Christie's practical class. Students' interactions concern application of process skills.

Kerstin *Just put it [a leaf] on the tile. You open it up when it is on the tile.*
Erika *[Puts the leaf on the tile and unfolds it. The leaf has lost most of its green color.]*
Ben *Where is the iodine? [reading from the manuals, Ben poses a rhetoric question, reach for the iodine bottle and passes it over to Erika.]*
Erika *[Takes a second leaf out of water bath.]*
Ben *[Pours iodine—seven drops on the leaf Erika spread on the tile—covering the whole leaf with iodine solution.]*
Kerstin *You cannot see the difference between the original and …*
Ben *But we won't see anyway. [Pours more iodine solution, till the whole leaf is covered.]*
Theres *Leave it for a while.*
Christie *What are you going to do now with excess iodine solution?*
Carol *Yeah, ask him that, ma'am.*
Erika *[Has taken the second leaf from the water bath and spread it on the tile next to the first leaf.]*
Christie *What will you do with the excess iodine [on the leaf]?*
Ben *Pour water.*
Johan *Now do it.*
Ben *No, wait first. [Laughs.]*
Christie *It won't have an effect on your results when you get it off?*
Ben *No, ma'am. [Looking for affirmation from the teacher.]*
Christie *Yes [said in affirmation to Ben's correct answer]. Yes. It is true, it will not change the colour.*
Theres *Will it?*
Ben *No.*
Kerstin *It won't change it [the leaf.]*
Christie *Why not?*
Kerstin *We are actually washing it off.*
Christie *What color will it change to?*
Carol *Inside?*
Christie *What is inside?*
Kerstin and Carol *Cells.*
Ben *Inside the cells.*
Christie *So if you rinse the surface, it will not have an effect?*
Class *No. [Chorused by students.]*
Christie *Washing out iodine on the surface will not have an impact, ne?*

The pattern of student-student interactions, with an occasional statement by the teacher, in Episode 2 is affected by the relatively large number of students in the group. The interactions are diffuse and do not follow a pattern. Sometimes a response (R) is followed by an action (A), or an action (A) follows a response

(R). The exploratory discussion concerns handling materials and apparatus while performing the process skills (e.g., Kerstin's instruction to "just put it on the tile. You open it up when it is on the tile") and issues they were unsure of Ben's asking "where the iodine is", it is part of the lesson but it is merely an incidental procedural detail. It is not directed towards understanding the subject content. Theres's asking, "Will it [change color]?"). Their discussion also provides explanations and evidence about what was done or observed (e.g., Kerstin's observation that "you cannot see the difference between the original and …") and makes suggestions about what should be done to complete the task (e.g., Ben's noting that "we won't see anyway, and Theres's suggestion to "leave it for a while"). The students' manner while providing suggestions, making explanations, and questioning each other signals what step needs to be taken.

In Episode 3, students' communication strategy is networked in such a way that they assist one another. The exploratory discussions are diffuse in this group with many students compared to the group with fewer students.

Episode 3: General food test: apple sample

Episode 3 is taken from the middle of a lesson led by Jarijo, toward the end of the activity. Students sat in different small groups – ranging from three to eight students of their choices. The biggest group has eight students while the smallest has three students. Each group received a set of test tubes as well as an unknown powder of a food sample. Each group has to carry out an emulsion test, Benedict's test, Biuret test and an iodine test by using the unknown food sample. Water and chemical solutions were provided for each group. The students were expected to carry out each test on a small amount of the unknown food sample. See Appendix A: Practical 24. The researcher opted to observe a group consisting of only three students as it was easier to follow the discussion of three students than more than three.

Willem *We need to have a pulp.*
Chris *Yeah. [Grinds apple pieces into pulp.] Get water from the tap.*
Willem *It won't be necessary. [Grinds pieces further into pulp.]*
Benny *What?*
Chris *Get water from the tap, yes.*
Benny *[add iodine directly to apple pulp.]*
Willem *Watch this color change. Is [it] still yellow, or what is the color change?*
Chris *No change. [Continues to grind apple pieces into pulp.]*
Willem *No change? Are you serious? No change? [Test tube 1 shows no color change. Iodine is also yellow. It must change to black-blue in this one.*
Benny *In this one? [Points to test tube 1.]*
Chris *This one is negative.*
Willem *No, in starch test.*
Benny *What color is starch test?*
Willem *It must go black-blue.*
Benny *So we are getting color change or [it] must go clear?*
Chris *Not really.*
Willem *[Puts apple pulp into all four test tubes.]*
Chris *Let us first put the stuff [apple pulp] in all of them.*

Benny *OK [Adds water to all test tubes, trying to pour an equal amount into all; only the first test tube has been cleaned. Then adds chemical reagents to each test tube in the correct order as follows: ethanol, Benedict solution, Biuret test (Fehling A and B) solutions and iodine solution.]*
Willem *[Shakes all test tubes to mix their contents.]*
Summary of the researcher: So far, everything has gone smoothly. The hot water bath is ready
Willem *Now you add the reagents. This is alcohol.*
Benny *[Takes test tube 2, adds alcohol and Benedict's solution droplets to it.]*
Willem *[Adds iodine solution droplets to test tube 2, puts it into hot water bath.] What is that?*
Benny *Benedict's test.*
Summary of the researcher: they added wrong solutions to test tube 2 and the color has changed from blue to green. They did not follow the procedures.
Chris *No. What have you done?*
Summary of the researcher: they carried out a wrong procedure. They did not read at all. They just added all the reagents to test tube 2 but then realize that they did a mistake. They literally added ethanol and Benedict solution to the apple pulp.
Willem *[Reads the manual and finds out that they used wrong reagents in test tube 2.] Ma'am, where is Fehling A?*
Jarijo *This is Fehling A and Fehling B. Add five drops of each.*
Chris *Let us read first. [Pages through the manual, and cleaned all test tubes.]*
Benny *Now we will do the emulsification.*
Chris *Work with alcohol. Bring the alcohol. [Reading from the manual.] "Look at test tube 2; is it changing color?" Is this starch test? Which one is this one? [Test tube 2 is in hot water bath.]*
Benny *Is milky.*
Chris *You mean there is fat in it?*
Benny *Is milky. [Difficult to judge whether the solution is cloudy because it reacted with a reagent or because the apple pulp is in suspension.]*
Chris *Is just the same.*
Benny *Yeah, is just the same.*
Chris *This is alcohol. [Points to test tube 1.]*
Benny *Emulsification, yeah.*
Chris *What color is this? [Points to test tube 2.]*
Benny *Orange.*
Willem *Glucose test?*
Chris *Yeah, is glucose test. [Pages through the manual.] And this one? [Points to test tube 3.]*
Benny *Is like blue.*
Chris *Is not blue.*
Benny *Is blue—is Benedict's solution.*
Chris *Is not blue.*
Benny *Green blue.*
Chris *There is no such a thing in here. [Pages through the manual.]*

Benny *Yeah. What color is that?*
Willem *Purple?*
Benny *Yeah, this is negative.*

The pattern of interactions in Episode 3 reveals a typical I-R-E-R-E chain. Episode 3 has three different exploratory moments. In their exploratory discussion students discuss procedures, observing and recording results, and interpreting experimental results. For example, "We need to have a pulp" signals that they should grind the apple pieces into a pulp; that is, they need to deploy the manipulative process skill. Students speak about the experimental results, and the last part of the discussion centers on interpretation of results. Lastly, they notice an error in the way they followed the procedures because the results they obtain are not what the manual says they should get. Thus, their exploratory discussion is on (a) practical procedures, that is, performing process skills; (b) observed results, that is, the color change; and (c) a realization of the importance of following manual procedures so as to know what to expect.

Table 3 summarizes the student-student interactions in the group experiments. Each of the three episodes showcases different periods in the lessons, and the students' actions reflect this; that is, students perform different tasks in each episode because they are in different parts of the practical activity. For example, during the first moments of the lesson, the discussion focused on manipulation of materials and apparatus and performance of process skills. The discussion shifted from procedures to making observations and interpreting results. Such a demarcation of activities has been observed during student-student interactions in group experiments (Beeth, 1998).

Table 3 shows that the pattern of interactions across the three episodes remains basically the same, that is, an I-R-E-R-E-R-E chain, although the focus of the discussion changes as the lesson moment changes. The group with many members appears to deviate from the normal pattern of interactions. Some members of the group dominate the discussions while others are much less active. Such a pattern of communication may inhibit other students from engaging in activities. The student discussions in Episodes 1 and 3 reveal a need for Jarijo to do more to structure students' roles and responsibilities and provide more guidance within the groups (McNeil & Krajcik, 2008). As noted earlier, the episodes are not all from the same lesson, from the same classroom, or supervised by the same teacher, but they represent events within the lesson moments in a similar manner. For example, every lesson has an introduction, main moment of presentation, and a concluding moment. Episode 1 is a typical example of what takes place during the first part of a group experiment, and episode 2 represents what takes place during the middle part. Episode 3 encompasses the last section of the second lesson and the concluding section. Table 3 also shows that the focus of discussion in Episode 1 and Episode 2 remains the same. Students discuss procedures and the use of materials and apparatus. However, the focus of discussion in Episode 3 changes from procedures to resources and then to observation and interpretation of results. Students appear to use different strategies in exploring ideas and establishing meaning during the learning process. The following themes emerge: questioning, explaining, offering ideas, and criticizing and reinforce each other's ideas. The offering of new ideas or answers and questioning them is common and appears across the three episodes. The act of explaining took place in Episode 2.

In analyzing the learning instances within the three episodes, it is apparent that pattern of interaction, organization of duties, participation by students, and negotiation of meaning differ from group to group and from one practical activity to another. Learning in student-centered classes is a process of active engagement to construct knowledge, and development of process skills, and use of scientific tools.

Table 3: Student-Student Interaction in a Group Experiment

		Episode 1 (Teacher is Jarijo)	**Episode 2 (Teacher is Christie)**	**Episode 3 (Teacher is Jarijo)**
Pattern of interaction	Oral and nonoral (actions)	I-R-E-R-E-R-E chain; one student dominates the discussion	I-R-E-A-R-A-R-E-R chain, that is, diffuse chain; some learners dominate the discussion	I-R-E-R-E-chain; equal participation in discussion
Focus of discussion	Procedural	✓	✓	✓
	Resources	✓	✓	✓
	Observation	NA	NA	✓
	Interpretation of results	✓	✓	✓
Type of exploration	Questioning ideas	✓	✓	✓
	Explaining ideas	NA	✓	NA
	Criticizing ideas	✓	NA	✓
	Offering an idea/answer	✓	✓	✓
	Reinforcing responses	NA	✓	✓

Note. ✓ = applicable; NA = not applicable.

Learning does not take place in a vacuum but is negotiated socially and culturally as well as through the medium of language (Roth, 1995; Zady et al., 2003; Richardson, 1997; Hodson and Hodson, 1998a; Staver, 1998; Nakhleh et al., 2002). Examination of the three episodes of group experiments reveals that students have opportunities to discuss and negotiate meaning among them. Students gain knowledge by participating in student-to-student discussion, not with the teacher. When students work on a group task, they learn and develop new knowledge. Mortimer and Scott (2003) argue,

The process of learning and developing that is being described here is not one that involves ideas being transferred directly from teacher to student, parent *to child or friend to friend. What is involved, for each participant, is an ongoing process of comparing and checking their own understandings with the ideas that are being rehearsed in the social plane.*

— Mortimer and Scott (2003, p. 10)

The students assist and guide one another in trying to make meaning of what they are learning, that is, about the language of science (exploratory talk), the skills that they need to perform, the procedures that they need to follow, the materials that they need to use, and the distribution of responsibilities to members of the group (Roth, 1995; Bennett, 2003; Jones, 2000). The focus of interest here, as Roth (1995) puts it, is on "learning which is viewed as an apprenticeship in the practices of a culture" (p. 174).

b) Teacher Demonstrations

Student-student interactions during teacher demonstrations at School B are minimal. The –teacher only reads procedures, provides measurement amounts of food substances, and tells students when to record observations. Even the tables on which students record the observed results are constructed by the teacher. Table 4 lists process skills and who performed them.

Table 4: Intended versus Implemented Process Skills Performed by Students during Teacher Demonstrations

	Intended process skills	**Performer of implemented process skills**
Skill 1	a) Follow sequence of instructions; b) Use appropriate techniques; c) Handle apparatus and materials competently; d) Have regard for safety.	a) teacher and a few students b) teacher c) a few students d) teacher and a few students
Skill 2	a) Make and record estimates; b) Make and record observations; c) Make and record measurements accurately.	a) not performed b) all students c) teacher and a few students
Skill 3	a) Handle and process experimental observations; b) Handle and process experimental data; c) Deal with anomalous or inconsistent results.	a) all students b) not performed c) not performed
Skill 4	a) Apply scientific knowledge and understanding to make interpretation from practical observations and data; b) Apply scientific knowledge and understanding to draw appropriate conclusions from practical observations and data.	a) all students b) all students
Skill 5	a) Plan and design investigation; b) Carry out investigations; c) Suggest modifications in the light of experience.	a) teacher b) teacher (design) and a few students (carry out) c) not performed

Skill 6	a) Make and record estimates; b) Make and record observations; c) Make and record measurements accurately.	a) not performed b) all students c) teacher and a few students

Table 4 shows that teacher demonstrations seem to provide opportunities to students to exercise Skill 2f; Skill 3h; and Skill 4k and l. Students had few opportunities to develop Skills 1 and 5. In addition, the teacher did not alert students about anomalous results. Teacher demonstrations would seem to benefit only those students who assisted the teacher. Skills such as Skill 1, Skill 2e and g, Skill 3i and j, and Skill 5 as indicated in the NSSC H- and O-levels. H- refers to Higher level and O- to Ordinary level. Biology syllabuses were unattainable by all students because they were performed by the teacher. Episode 4 illustrates the types of skills performed by Lena, the biology teacher at School B during demonstrations. Recall that Lena's laboratory is also her classroom and has very limited equipment. Pertinent instructions are underlined.

Episode 4 *Test for Vitamin C.*

The teacher provided different food samples such as uncooked potato, onion, peanut and orange. Lena called four students in front of class. These students prepared the food samples into a pulp so that each food sample was ready for further testing.

Lena: *So, we are <u>not</u> going to <u>use teat-pipettes,</u> but we have syringes because we don't want you to dye your hands. What is going to happen? <u>Put on gloves on hands</u>. These are the beakers. [Calls a few students to join her in front. She gave instructions to the few students in front and the students performed the procedure as directed by teacher. Grind the food each food sample separately and pour into a beaker. Each one of them (students) will pour their substances into the beakers. They will pour equal amount of each substance every time.*

[Student assistants come up to Lena's workstation and prepare to assist her.]

Lena: *I will <u>pour 2 ml of the dye in each beaker</u>. They [the student assistants] will pour 2 ml of food solution every time. They are going to do it more or less four or five times.*

Most of the process skills performed by Lena involve lower cognitive levels, such as manipulating apparatus and materials, reading procedural instructions, and following procedural instructions sequentially. Other process skills such as experiment replication thinking skills, variable identification, instrument choice, discussion of observable results, and graph and table construction are lacking in the demonstration lesson. Table 5 lists process skills that were performed by some students who assisted the teacher during teacher demonstrations. Thus, Table 5, below somehow a different focus from tables 1 and 4above because the focus was on the students who were assisting the teacher. Some activities were also added that are not in table 1 (syllabus), for example. The reason may be attached to a slightly different context as the one used by Millar, Le Marechal, and Tiberghien (1999) for the framework. Some skills that were not listed in table 1, although carried out by some or group of students (skills added are bolded now). Therefore, table 5 looks different from the rest of the tables because of the special editions.

Table 5 indicates that only a few students performed the majority of the process skills, such as following instructions, handling materials and apparatus, making measurements, and carrying out practical tasks. Most of students observed and listened rather than handled apparatus and materials or followed instructions. In practical work, observation is regularly conducted by teachers and students. Although an important aspect of practical work, observation must be accompanied by theories. Wellington (2000) asserts that no student can observe events and make meaning out of them without a framework. He further argues that observation is hardly pure, and it is complex. Meaningful observation is theory driven, and students need to be told, for example, what color changes to look for. At a time, ten to twelve students were called to come and stand in front of class. The teacher together with the students who assisted her will carry out an activity, show to these students, then repeat the same activity to another group of students until all students in the class have a chance to observe how the practical activity was carried out. The next two episodes illustrate with underlining this aspect of providing information to students.

Table 5: Student Activities during Teacher-Demonstration Lessons

	Skill category of student activities	**Activity**	**Performer**
1	Practical skills to:	a) Follow sequence of instructions	A few students
		b) Handle materials/apparatus	A few students
		c) Collect materials/apparatus	None
		d) Make observations	All students
		e) Make measurements	A few students
		f) Read procedures	All students
		g) Complete worksheet	All students
2	Carrying out demonstration tasks	a) Carry out a task individually	A few students
		b) Carry out a task assisted by teacher	
3	Recording data or observations	a) Individually	All students
		b) In small groups	None
4	Interpreting and make conclusions	a) Individually	All students
		b) In small groups	None
5	Discussing ideas	a) With peers	Some students in small groups
		b) With teacher	None
6	Reporting experimental findings	a) Individually in writing	All students
		b) In small groups in writing	None
		Orally	None

Episode 5 Testing Food for Starch

Lena: *This is a starch test. The reagent is iodine. So I am going to use a blocking tile. [Puts the blocking tile with 12 small holes on the table.] Put one spatula from each food sample at the holes at the corners on the blocking tile. What is this called? [Holds up a blowing pipette.]*

All students *Pipette.*

Lena: *Yes, it is called a blowing pipette, because you are blowing through it. Iodine has a brown color, and if a substance we are looking at contains starch, we are expecting a blue to black color.*

Episode 6 Testing Food for Starch

Lena: *So we are looking out for a bluish color. You can see that this is the iodine color [Points to the iodine-solution bottle.]*

Student1 *We are looking for a black or blue color, ne?*

Lena: *You make your choice.*

Student2 *Is this the potato, ma'am? [Points to the tile (no labels identify the food samples).]*

Lena: *Yes. This is the potato, peanut. [All food samples crushed into a pulp and put on different wholes on a white tile. The teacher pointed sequentially to two holes with two different food samples, that is, potato pulp and peanut pulp.] Maybe I should add more peanut, just a little bit.* [*Adds peanut to another hole on the tile and then three drops of iodine solution on it.*]

In both episodes, Lena provided information to students that they needed so as to make meaning out of what they observed during the demonstrations. In addition, the descriptions of what was to be observed went beyond language (Ogborn et al., 1996). For example, Lena gave iodine as a blueprint for students to use in deciding whether the color change was the expected one.

In Episode 5 Lena does not involve students in dialogue, as she did in Episode 6. In Episode 6, Lena provides opportunities for students to communicate with her. However, instead of being more accommodating and probing or involving students in argumentation (Ogunniyi, 2006; Abd-El-Khalick, 2005; Erduran, 2006), Lena responds to the student in a way that does not provoke discussion. Providing opportunities for mediating, scaffolding, and making meaning at the social or intermental plane in the classroom would benefit Lena's students.

Solomon (1994b) argues that discussions (prelaboratory and postlaboratory) allow students to get second opinions from other students, assist one another in completion of practical tasks in time, and make sure that they are on the right track. Lena carried out teacher demonstrations without providing opportunities for discussion of expected results or anomalous results. The students' responses in the episodes make clear that discussions give them opportunity to learn from one another. As they listen to others they tend to develop a better understanding of phenomena. In Solomon's (1994a) view group discussions in practical work (a) give students the opportunity to negotiate meanings, (b) provide the opportunity to assist one another, and (c) help students construct knowledge at a social level.

During the classroom observations I made, the teacher demonstrations denied students valuable opportunities for the construction of knowledge at a social level, as well as not allowing the teacher to diagnose students' misconceptions or alternative conceptions (Driver et al., 1994). They did not provide opportunities for discussions. Solomon (1994a; 1994b) finds that teachers' preoccupation with the protocols of demonstrations often prevents them from giving sufficient opportunities for discussions critical to students' conceptual development. Modifying the teacher demonstrations presented here by having the teacher follow the austere prescription of being neutral and not trying to influence students' observations would have benefited the students. In general, discussions are essential because they may suggest new meanings to others. In addition, discussions help in the planning and design stages of practical work and in sharing personal perspectives on the topic under discussion.

Furthermore, in Episode 2 the process skills that Lena performed at School B were at a low-process-skill level. High-level conceptual skills were the domain of the teacher rather than the students, whereas the teaching approach needed to be student centered rather than teacher centered (Trumbull et al., 2006; Boz and Uzuntiryaki, 2006; Oh, 2005; Martinez-Lusada and Garcia-Barros, 2005). Teacher demonstrations that lack dialogue with students do not support development of higher-level process skills (Ramorogo, 1998; Wu and Hsieh, 2006; Chin, 2006; Morge, 2005). Observing color change without dialogue might not be enough for students to make meaning. Teacher demonstrations tend to use skills that the teacher feels confident of managing and performing (Ogborn et al., 1996; Frost, 2005). Lack of appropriate planning (Frost, 2005), preferred teaching style or behavior (Harlen, 1999; Hofstein et al., 2005), and lack of engagement of students in dialogue (Frost, 2005) might provide some unforeseen problems to students while carrying out a demonstration. What I meant was creating a problem for students when taking practical examinations where they have to perform the skills that were performed by the teacher of those students who assisted the teacher. Thus, the preferred teaching style, in this case, teacher demonstration, provided fewer opportunities for students to acquire the process skills as intended by the curriculum. Lack of engagement in a dialogue, for example, if a student does not follow what have been said or done by the teacher and the teacher does not provide opportunities for dialogue, students might leave the laboratory without really understanding what they were doing. One of the limitations of practical work is that is does provide an explanation by itself. Thus, dialogue student-teacher or student-student is essential during demonstrations.

Conclusion

The biology teachers in this study used two types of practical approaches: group experiments and teacher demonstrations. Practical activities conducted by the teachers and students seemed to have greater potential for enhancing the process skills students need to pass the NSSC practical examinations. Teacher demonstrations focused on a limited number of process skills such as making observations, recording observational results, and writing conclusions, whereas group experiments offered more opportunities to students to exercise the process skills the Namibian biology curriculum intends to instill. In addition, interactive teacher interventional strategies during lectures and group experiments appeared to provide more opportunities for students to discuss and negotiate subject content knowledge at the intermental plane compared to the authoritative interventional strategies I observed in teacher demonstrations.

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